Reconstructing vegetation diversity in coastal landscapes

This thesis will be published as a volume in the series Advances in Archaeobotany.

English text editing	Suzanne Needs-Howarth, Toronto
	Annette Hansen, GIA, Groningen
Book and cover design	Christine Klein, Bremen www.christineklein.nl
Photos	Mans Schepers, René Cappers and Inger Woltinge
Production	Roelf Barkhuis www.barkhuis.nl
Financial support	Stichting Nederlands Museum voor
	Anthropologie en Praehistorie

© 2014 Mans Schepers

Reconstructing vegetation diversity in coastal landscapes

PhD thesis

to obtain the degree of PhD at the
University of Groningen
on the authority of the
Rector Magnificus Prof. E. Sterken
and in accordance with
the decision by the College of Deans.

This thesis will be defended in public on

Thursday 15 May 2014 at 16.15 hours

by

Mans Schepers

born on 27 June 1983
in Groningen

Supervisors
Prof. R.T.J. Cappers
Prof. D.C.M. Raemaekers

Co-supervisor
Dr. ir. R.M. Bekker

Assessment committee
Prof. W. Kirleis
Prof. J.H.J. Schaminée
Prof. R. Van de Noort

Aan Nicolien Bottema Mac-Gillavry en Henk Woldring
Voor het wijzen van planten en het planten van wijsheid
Opdat die ooit bloeien moge⋯

Contents

General introduction

PEOPLE AND VEGETATION | Reconstructing vegetation is far from a walk in the park – yet it is a prerequisite for a fuller understanding of past human behaviour in all its aspects. The exploitation of the landscape is not restricted to the direct use of plants. It is the grass we will not let grow under our feet, the forest we cannot see for the trees, and the nettle we are willing to grasp. To reduce vegetation to the berries we chew, the meadows we graze our livestock on, and the oaks we fell to support our roofs is an anthropocentric simplification of the complicated interaction between humans and their environment. This relationship is relevant to, and has been studied from, a variety of perspectives, both historical and contemporary (Sukopp 1969).

      Traditionally, archaeological studies (and archaeologists) have split into two camps. On the one hand, there are the so-called 'specialist studies', such as ceramic analysis, lithic analysis, and zooarchaeological analysis. On the other hand,

there are the more general studies, in which various aspects of one period are brought together. In this tradition, the study of past vegetation would be regarded as a specialist palaeobotanical (also known as archaeobotanical) study. However, the relevance of the natural environment for understanding human behaviour has long been acknowledged by more generalist archaeologists, in some cases as a result of the archaeologist's background in biology or physical geography (two Dutch examples are Louwe Kooijmans [1974, 1985] and Waterbolk [1954]).

Two main research questions underlie this study, of which the first governs the second: Is it possible to improve upon the reconstruction of past vegetation at the most detailed level? To answer this first research question, several approaches are adopted. First, the potential of applying both recent and long-established methodology and data from present-day vegetation ecology to archaeobotanical data is explored. Modern ecological field studies are an essential element for the interpretation of the archaeobotanical record (Butzer 1982, 171–172). Second, the relationship between some frequently studied types of archaeological contexts and their botanical composition (as opposed to standing vegetation) is studied in detail. It is alleged that it is possible to successfully address past vegetation composition by seeking novelty in the analysis, rather than by seeking new proxies (stage 5 rather than 4 in Fig. 1.5). In this study, the emphasis lies on the reconstruction of vegetation in wetland environments where an open coast profoundly influenced landscape dynamics.

The second research question follows directly from the first: Does a more detailed reconstruction of vegetation enable us to expand our understanding of past human interaction with the landscape? To explore this, new approaches are applied to two coastal wetland areas in the northern Netherlands, where several botanical and geological studies dealing with landscape and vegetation have been carried out previously by other researchers. These areas, the Swifterbant river system and the terp region, are the subjects of major lines of research by the Groningen Institute of Archaeology. Having already been studied intensively, these two regions combine the challenge of

being able to add original results and ideas with the benefit of a substantial corpus of available data. Both new primary data and previously published data are used, thus making internal reports and reports resulting from Dutch commercial archaeology accessible to the international community.

THEORY OF VEGETATION RECONSTRUCTION | In order to be able to address the difficulties we encounter when dealing with the reconstruction of past vegetation, it is essential that we define what vegetation actually is and how it differs from a list of (quantified) taxa, as typically results from archaeobotanical analysis. The difference between raw archaeobotanical data and past vegetation is analogous to the difference between the terms 'flora' and 'vegetation'. The primary difference lies in the spatial component. The flora of a certain area is a list of taxa encountered in a certain area. While walking through this area, one would notice that these plants are not randomly distributed; they are, in stead, grouped in a systematic way (Meltzer and Westhoff 1942, 17). Vegetation is the spatial distribution and coverage ratio among the taxa of a flora. Whereas flora is thus a rather abstract concept, vegetation is the factual spatial manifestation of plants, high or low, open or dense, that one can actually walk through (Cappers and Neef 2012, 93; Westhoff *et al*. 1995, 15). Archaeobotanical data, which are basically a list of identified (quantified) plant taxa, can be considered an incomplete past flora. The complex relationship between archaeobotanical samples and vegetation is visualized in Figure 1.1.

A number of major differences exist between taxon lists (at whatever taxonomic level) and reconstructed vegetation. First, the axes of the matrix summarizing the results differ, and so do the units of measurements in which these are expressed. Whereas vegetation is mostly expressed in 'coverage' per defined surface area ('relevé'), archaeobotanical data are expressed in 'number of remains' per sample. Number of remains is the most common form, but alternatives do exist (e.g. categories of number of remains, presence/absence). In addition, synoptic tables of vegetation descriptions can be designed in various ways (Schaminée *et al*. 1995b).
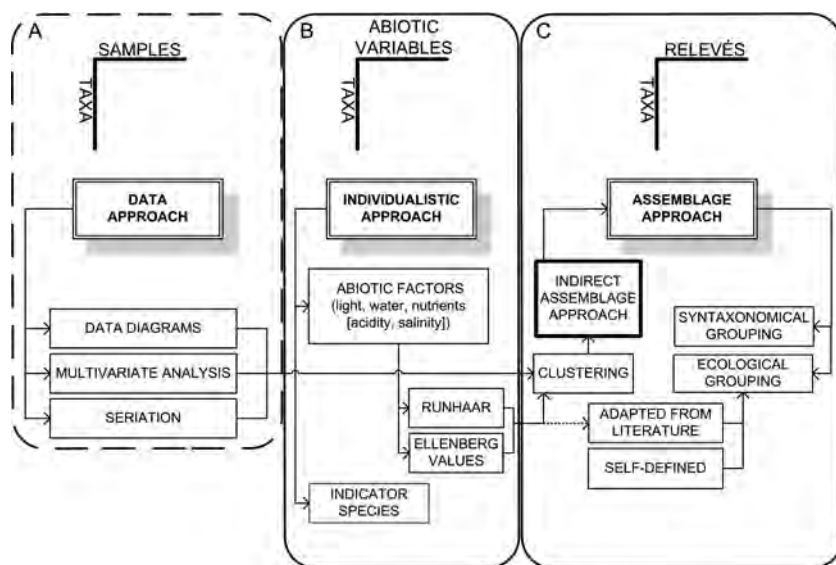
Figure 1.1 Diagram showing the three steps that may be used to transform the composition of archaeobotanical samples into vegetation

Taxon lists already differ from past flora at the qualitative level. This difference primarily concerns taxa that are present in the past vegetation but are lacking in the archaeobotanical archive. The cause may be differences in seed production, seed dispersal, and preservation conditions, or the fact that some taxa are hard to distinguish at a lower taxonomic level. Moreover, the palaeobotanical archive may also include taxa that were not part of the vegetation during the period under study – for example, when erosion of peat layers results in the inclusion of *Sphagnum* leaves in samples from a salt marsh environment (see Chapter 5).

Additional complications are that most archaeobotanical samples represent a mixture of vegetation types and that many factors, known as formation processes, influence the chances of remains ending up in an archaeological sample (Miksicek 1987; Willerding 1991). All of these formation processes combined are sometimes referred to as taphonomy, but this is strictly spoken not exactly the same thing (Gifford 1981). In this study, site formation and taphonomy are used interchangeably. The model presented by Cappers (1995a) discusses the formation

of seeds in the soil. Other contexts, such as drift lines, dung layers, hearths, or post holes, may be subject to profoundly different processes that determine sample composition (e.g. Charles 1998; Out 2012; Van Vilsteren 1984; Wolters and Bakker 2002). Furthermore, because many vegetation types gradually merge into others, the translation of numbers of remains in a sample into relative coverage is invalid for reasons that go beyond differences in taphonomy among species. For example, the remains may represent a sequence of vegetation types from a *limes divergens* (Westhoff and Van der Maarel 1978, 303–305), in which the same taxa occur, but in different ratios (Fig. 1.2).

Figure 1.2 Co-occurrence of White beak sedge *(Rhynchospora alba)* and Brown beak sedge *(Rhynchospora fusca)*. Although the white-fruiting species clearly clusters on the left and the brown-fruiting one on the right, individuals of both species occur within the cluster of the other. The spatial distribution of the two species cannot be directly calculated from the number of remains when an accumulation deriving from these two vegetation zones ended up in one sample, but should be deduced from their present-day ecology (Langaarveen near Norg, The Netherlands, July 2013)

If the goal is indeed to reconstruct past vegetation, the challenge is to get from the sample(s) (Fig. 1a) to an idea of the possible combination(s) in which the identified taxa may have occurred in the past (Fig. 1c). Information on past vegetation can be extracted from patterns present in the data itself. This could be termed the 'data approach' (Fig. 1.1a). Figure 1.1 shows some possible examples, but many more options are possible. In its most basic form, this approach could also be applied to the data

without actual identification of the remains; for example, by analyzing a matrix composed of samples and a number of different so-called 'type identifications' (ecological characteristics of taxa play no role yet). This generally requires a large number of samples, allowing for statistical tests or some sort of probable meaningful visualisation of the data. Actual statistical testing of the raw data is rarely performed (Jones 1991, 76), partly due to the many uncertainties encountered when dealing with archaeobotanical remains. Proposition 2 from the study by Lange (1988) (my translation) is of particular interest here: "The results of archaeological research are generally open to multiple interpretations. Applying statistical tests does not change this." Multivariate statistics are commonly used to show and visualize patterning in the data (Brinkkemper 1993; Cappers 1995b; Lange 1988). Naturally, the raw data are frequently combined with ecological characteristics of the identified taxa to show whether environmental characteristics explain the patterning, or, as is the case for most pollen diagrams, to group ecologically related taxa in order to improve the possibilities for interpretation.

A final variation on the data approach is to use characteristics of the plant remains themselves to identify the possible co-occurrence of taxa. A prime example, and one that is used in both study areas of the present study, is the identification of crop weed vegetation from the association of burnt cereals and wild plants (Out 2009a, 381–389; Pals 1999, 139; Wilson 1984). Another example is plant remains from waterlogged deposits of which several taxa show comparable fragmentation as the result of crop processing activities (e.g. Out and Schepers 2011, 73; see also Box 1).

Evidently, it is necessary for us to know the ecological and sociological characteristics of the identified taxa in order for us to be able to address past vegetation. This can be done through either the individualistic or the assemblage approach (Fig. 1.1b and 1.1c), dealt with at length in Chapter 2. Because vegetation is by definition an assemblage, vegetation reconstruction can only be achieved in the final stage of Figure 1.1 (c). This can, however, also be done indirectly, by using individual species values on abiotic factors. When one does not aspire to

actually reconstruct vegetation but merely wants to character-
ize the environment and allow for an easy comparison of sites or
periods regarding a specific environmental condition, one can
use indicator species (e.g. Behre 1991; Cappers 1994). The use of
indicator taxa is common practice in palaeoecological analysis
(e.g. Griffiths 2007; Kenward and Hall 1997; Zagwijn 1994).

To describe past vegetation, there are basically two ap-
proaches. One uses so-called ecological groups. Using ecologi-
cal groups will easily lead to simplification. Species with broad
ecological ranges, in particular, may be inadequately appreci-
ated by this approach (as pointed out by Behre and Jacomet
[1991, 83] and Tamis *et al.* [2004, 111]). An example of such a
species, stinging nettle *(Urtica dioica)*, is presented in Figure
1.3. In the system presented by Arnolds and Van der Maarel
(1979), it is assigned to category 8b: the fringes of nutrient-rich,
non-calcareous, humic, moderately moist soil. Ellenberg *et al.*
(1991) assign the nettle to nitrogen-rich herbaceous vegetation
(category 3.5).
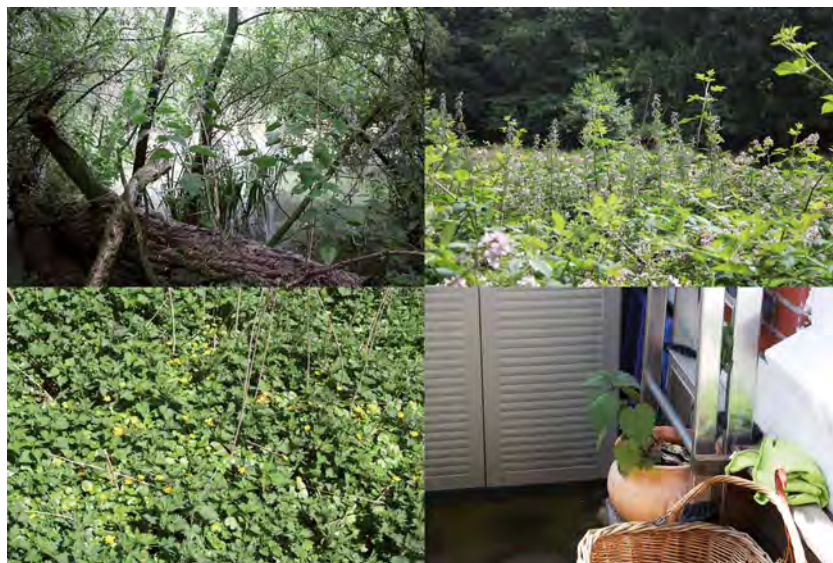
Figure 1.3 Stinging nettle *(Urtica dioica)* in four different habitats. Clockwise from top left: (1) colo-
nizing a White willow *(Salix alba)* trunk in a willow carr (Millingerwaard, The Netherlands, July 2013);
(2) in a bramble thicket (Smeerling, The Netherlands, July 2013); (3) invading my balcony (Groningen,
The Netherlands, July 2013); (4) in among Lesser celandine *(Ficaria verna)* (Anloo, The Netherlands,
April 2013)

These descriptions are very similar, both pointing out the link to high nutrient availability. Both groups of authors, however, do also link their categorization to the syntaxonomic system. But whereas Arnold and Van der Maarel assign their group to the *Galio-Alliarion*, Ellenberg *et al*. assign it to the *Artemisietea*. The two syntaxa are very closely connected and share a great number of species (Weeda *et al*. 1999). The use of ecological groups leaves more room for the variety in growth locations available to this species. Therefore, great care is required when trying to apply the present phytosociological classification to a reconstruction of the past (Küster 1991).

However, using individually assigned labels as a starting point, instead of the entire assemblage in the sample, obscures the possibility of assigning the stinging nettle to some of the other vegetation types in which it may very well occur (though less frequently or even incidentally), such as thewillow carr, the alder carr, and bramble thickets.

Among the several published overviews dealing with the reconstruction of vegetation from archaeobotanical or palaeobotanical samples, the contribution by Behre and Jacomet (1991) and the summary of different approaches by Jacomet and Kreutz (1999, 143–153) present a good starting point. They rightly emphasize some possible hazards one may encounter when trying to reconstruct past vegetation, especially when using 'the present as a key to the past' (Behre and Jacomet 1991, 83; see also Chapters 2, 3, and 6). It is generally accepted that this *'uniformitarian assumption'* decreases in validity as the (assumed) anthropogenic character of the vegetation increases. The degree of dissimilarity to present vegetation types will also be higher when, as in this study, the emphasis lies on the reconstruction of vegetation at a high resolution – in other words, at a very local level. Nonetheless, it needs to be stressed here that virtually all quaternary palaeoecological reconstructions are based on uniformitarian principles (Clarke 2013, 539; Lowe and Walker 1997, 162). Because this study deals primarily with plant macro-remains, the following discussion regarding vegetation reconstruction primarily concerns that particular proxy.

In The Netherlands, numerous thorough studies have been devoted to the reconstruction of vegetation on a regional or higher level, mostly using a combination of palynology and geology (Van der Woude 1983; Casparie 1972; Van Zeist 1955). In other studies, palynology is used to analyze regional vegetation, whereas the analysis of plant macro-remains is primarily used for the interpretation of synanthropic vegetation, cultivation, and the gathering of wild plant food sources (e.g. Kooistra 1996; Gehasse 1995; Bakels 1978). In wetland environments, not least because of the preservation conditions they provide, plant macro-remains play a bigger role in the reconstruction of the vegetation, especially at a local or regional level (e.g. Bakels *et al*. 2001; Brinkkemper 1993; Cappers 1995b). A very detailed reconstruction of hydrosere vegetation succession, also predominantly based on plant macro-remains, was presented for the Noordoostpolder by Gotjé (1993).

LANDSCAPE, VEGETATION, AND THE EXPLOITATION OF COASTAL WETLANDS | This study focuses on reconstructing vegetation in wetland landscapes that were under a marine influence. The interaction between people and the natural environment in wetland landscapes is a widely and intensively studied subject in archaeology, and a growing number of handbooks and collected papers on the subject have become available, especially from the United Kingdom (e.g. Murphy and French 1988; Needham and Macklin 1992; Purdy 2001; Lillie and Ellis 2007; Menotti 2012; Menotti and O'Sullivan 2013). All of these stress the high biomass that was generally available in the areas concerned, of which vegetation is a – if not *the* – major component.

Because large portions of The Netherlands consist today, and consisted in the past, of wetlands, it is only to be expected that numerous studies conducted in The Netherlands deal with wetland environments. They concern, on the one hand, extensive excavation monographs, including chapters on the botanical remains (e.g. Eijskoot *et al*. 2011; Hamburg *et al*. 2013; Louwe Kooijmans 2001; Nicolay and Dijkstra 2008; Nieuwhof 2008a) and, on the other hand, a number of regional and/or chronological archaeobotanical overviews (Brinkkemper 1993, 2006; Buurman 1996; Gehasse 1995; Out 2009a).

From the point of view of vegetation reconstruction, it is important to acquire a thorough insight into the complex relationship between the different types of landscapes and their growth potential for different vegetation types. The factors of landscape formation and exploitation that play a role in this relationship have been laid out in Figure 1.4. For easy comparison, an underlying matrix of rows and columns has been added to the diagram. An (alpha)numeric code between brackets relates to this matrix, indicating what part of the diagram it concerns. The primary link between both regions under study here is that they are characterized by incidental, mainly seasonal, high water levels and flooding (A). These hydrological dynamics play a key role in the geomorphology of the landscape (B), the vegetation in different parts of that landscape (C), and the possibilities for exploitation of that landscape that were available to people in the past (D).

 With respect to flooding, four major factors play a role. The first – and most obvious – is the frequency and timing of flooding. Both strongly influence the landscape and people's activities therein (A1). The second is the intensity of flooding (A2). Highly dynamic floods can directly 'form' the landscape. Examples are the formation of crevasses; the development of new creeks (B3); or the erosion of landscape components, such as banks and ridges (B1). On the other hand, more intense floods can carry heavier particles, which leads to the formation of creek banks and ridges (A2, A3, B1). The source of the water flooding the landscape determines the potential sediment load (the third factor) and associated nutrient contents, as well as the salinity (the fourth factor). Both nutrient availability and salinity are major abiotic factors for vegetation (A4 and C; see also Fig. 1.1b).

 The landscape formed under the influence of these floods is considerably different in the two areas, but some of the main components are very much comparable, especially as they pertain to understanding the location of human settlements. In both areas, settlements occur at locations where the deposition of heavier particles leads to the formation of elevated and drier places (B2). In the Swifterbant river system area, these are the

river banks; in the terp region these are the elevated ridges along the coast (see below). After a while, a side-effect of this elevation is that these parts will flood less often, probably only during very intense storms (A and B). There are two possible solutions for humans to deal with these high water levels: (1) restrict habitation to the less dynamic times of the year or (2) adjust the landscape or settlement in such a way that (strong) floods need not be catastrophic for habitation and food production.
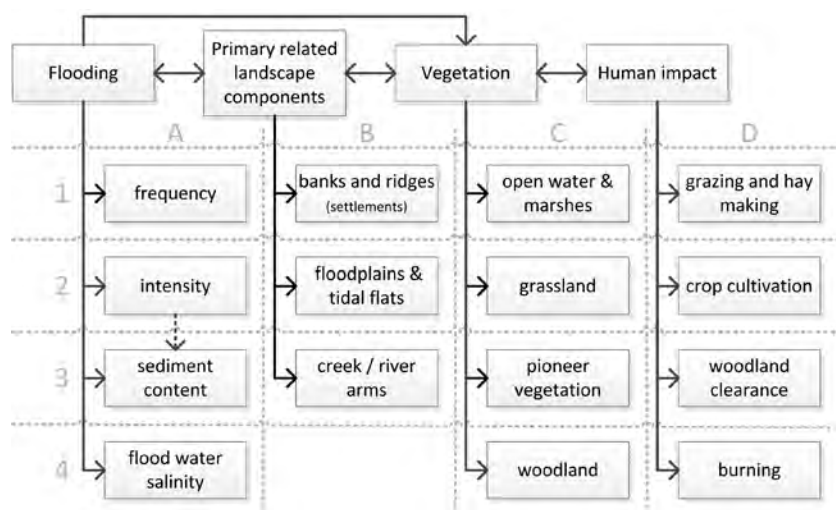
Figure 1.4 Relationship between flooding, geomorphology, vegetation, and human exploitation in the study areas. The underlying matrix serves for easy comparison with the text and Table 1.1

Higher, drier parts of the landscape will facilitate the development of other types of vegetation (C2, C4). Such vegetation is thus both directly and indirectly related to flooding. Flooding also controls the deposition of nutrients, which, in turn, influences vegetation. This vegetation can then serve as a sediment catcher, thus once again stimulating sedimentation (Eisma and Dijkema 1998; Stock 2011). A complex combination of multiple factors determines which vegetation types will develop in which parts of the landscape. In The Netherlands, no tree species are capable of dealing with highly saline conditions.[1] Hence, flooding with water with high salinity values will prevent the formation of woodland (A4 and C4).

Different landscape components and associated vegetation, such as grassland and woodland, facilitate human exploitation in various ways. Grasslands, *nomen est omen*, provide potential grazing grounds for livestock, a fact that is classically accepted as the primary reason for the colonization of the terp region (Van Gijn and Waterbolk 1984). Grazing, in turn, influences the grassland composition (C2 and D1), once again affecting the potential sediment catch (A and B).

High seasonal dynamics thus influence human behaviour in both areas. A classic matter of debate in both areas is the (im)possibility of cereal cultivation under these circumstances (D2) and, if cereal cultivation is deemed possible, what crops are best suited for the area (e.g. Cappers and Raemaekers 2008; Out 2008, 2009a, 2009b; Van Zeist 1989; Van Zeist *et al.* 1976). In both areas, this debate oscillates between the undisputed fact that the dynamics of the system cause plenty of nutrients to be deposited and the question of whether these dynamics were indeed confined to particular seasons or could be dealt with in such a way that crop failure could be prevented (A1 and A3). The various forms of exploitation mentioned in Fig. 1.2 are incomplete, but they do include the examples most relevant to this study. Many more activities must have been conducted by ancient people, and they will all have had their impact on the vegetation and the landscape.

METHODOLOGY | Figure 1.5 shows the various stages in archaeobotanical research. The first stage, the formation of the archaeobotanical archive, cannot be controlled. However, the sampling strategy, stage 2, can be based upon assumed possible formation processes. Specific contexts may be believed to represent only one plant community, whereas others may be assumed to be a mixture of different types of vegetation (Körber-Grohne 1967; Willerding 1991). The possibility of recent contamination is not taken into account in this study.

There are a number of methods for processing an archaeobotanical soil sample for plant macro-remains (stage 3), with the ones most frequently used being wet sieving and flotation. In a wetland environment, with samples in which non-charred

plant remains predominate, wet sieving is by far the most commonly used method (flotation being especially suited to charred remains). In both the Swifterbant and the terp region, dried out plant remains from large-volume samples recovered in the field with a big sieve mesh aperture are studied in addition to the wet samples. The wet samples are fully processed in the laboratory. The dried out plant remains mainly serve for the recovery of economic plants, which often have relatively 'large' remains (e.g. grain kernels, plum stones, and hazelnut shells).
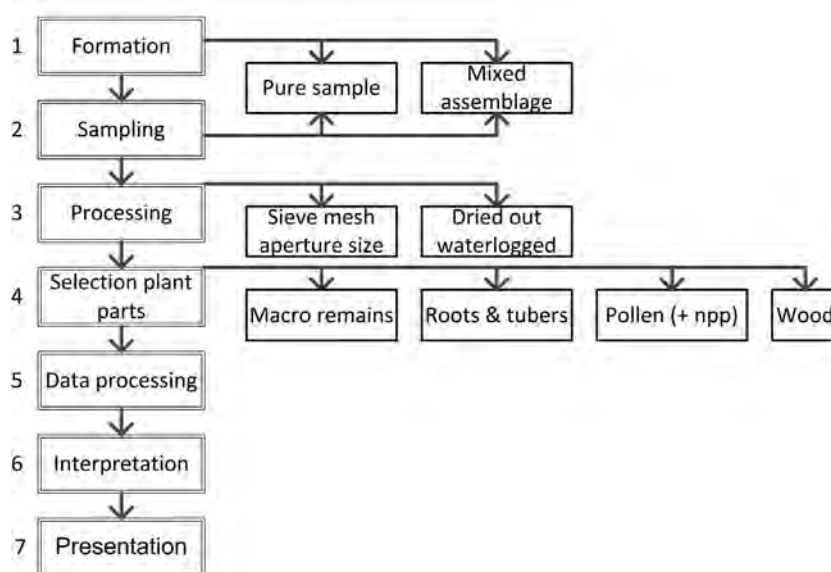
Figure 1.5 Diagram of main stages of archaeobotanical research. For details on data processing, see Figure 1.3

The proxy that is selected in order to answer the research questions affects the processing and possibly the sampling stages as well. The proxies mentioned in stage 4 of figure 1.5 are used in this study. The processing of the data (stage 5) for vegetation reconstruction is presented schematically in Figure 1.1.

Obviously, there are many more questions to be answered in archaeobotany than vegetation reconstruction alone. Reconstructing food preparation or the construction of dwelling structures will require other ways of processing and visualization.

ORGANIZATION OF THIS THESIS | The issues addressed in this study can be divided in three main categories: vegetation reconstruction (Fig. 1.1), landscape dynamics and exploitation (Fig. 1.4), and methodology (Fig. 1.5). Table 1.1 presents the occurrence of these categories throughout this study.

Chapter 2 presents an overview of various methods used in vegetation reconstruction, followed by the presentation of a new method. This method is used in Chapter 3 to reconstruct the vegetation in the vicinity of Neolithic Swifterbant Culture settlements and to address some major landscape-related archaeological issues. Chapter 4 presents an experimental study dealing with the relationship between the botanical composition of dung from hay-fed livestock and the source vegetation. Chapter 5 is an overview of 40 years of research on plant macro-remains from terp sites. Two boxes are presented in addition to the chapters. Box 1 deals with a classic example of a pure sample. Both the new method presented in Chapter 2 and a more classical approach to the data are used to characterize the vegetation from which this sample originates. This serves both to compare the methods and to emphasize that the vegetation reconstruction is improved by a combination of both approaches. In Box 2, it is argued that a ditch, being a context generally regarded to be almost the opposite of a pure sample, should perhaps be valued more, provided that the right ditch is chosen. Chapter 6 presents the conclusions and discussion, as well as some issues that could not be included in the other papers, but that are believed to be a relevant finding of this study. This final chapter also presents suggestions on how to deal with those issues in the future.

	Figure 1.1	Figure 1.4	Figure 1.5
Chapter 2	C	–	5
Box 1	A/B/C	A2/D2	1/5/6
Chapter 3	C	A/B/C/D1-3	1/4/5/6
Box 2	B/C	A3/B3/D2	1/2/6
Chapter 4	–	C2/C4/D1	1

| Chapter 5 | A/B/C | A/B/C/D1-2 | 1/5/6 |
| Chapter 6 | – | D2/D4 | |

Table 1.1 Occurrence throughout this study of aspects related to improving vegetation reconstruction (compare to Fig. 1.1), landscape dynamics and exploitation (compare to Fig. 1.4), and archaeobotanical methodology (compare to Fig. 1.5)

STUDY AREA AND PERIOD | The main research questions of this study are not directly related to a specific area. Nonetheless, the results are of major relevance to the two main research areas taken as case studies here, and these will therefore briefly be introduced. Samples from the sites of Noordbroek and Coevorden, dealt with in Box 1 and Box 2, are included as a methodological example. Their cultural background is not further explored. A basic map of the Northern Netherlands showing the locations of the studied areas is presented in Figure 1.6.

Swifterbant river system | The first region is the core area of the Swifterbant Culture. Following the reclamation of the Polder Oost Flevoland in the late 1950s, systematic geological and pedological research revealed a submerged system of waterways, banks, and floodplains. It was during the inspection of tali of ditches, dug into the freshly reclaimed land, that clear signs of human activities were identified in association with this buried river system (Van der Waals and Waterbolk 1976, 4). It was dr. J.A. Bakker from the University of Amsterdam who named the culture that these remains are associated with after the nearby village, Swifterbant (Peeters *et al.* 2004, 6). In this study, I concentrate on the vegetation in this river system during the Neolithic period (4300-4000 b.c). The area has been restudied intensively from 2004 onwards, as part of the New Swifterbant Project (e.g. Cappers and Raemaekers 2008; Devriendt 2013; Geuverink *et al.* 2009; Huisman *et al.* 2009; Prummel *et al.* 2009; Raemaekers *et al.* 2005).

The Swifterbant Culture is not restricted to this Swifterbant river system; nor did it function in isolation from other contemporaneous groups and cultures. Sites attributed to the Swifterbant Culture are known from Doel, Belgium (e.g. Deforce *et al.* 2013), to Hüde, Germany (Raemaekers 1999, 72-91 and ref-

erences therein). The culture covers the time span between ca. 5000 and 3400 B.C. Its place and function in the larger Late Mesolithic and Early Neolithic framework have been studied extensively by Raemaekers (1999; 2005). The end of the Swifterbant Culture is dated somewhat earlier in a recent, extensive discussion about its relationship to other Neolithic cultures (Ten Anscher 2012, 131–153). The most detailed archaeobotanical report available was published by Out (2009a). She incorporates the Swifterbant Culture in her comprehensive overview of botanical remains in Dutch wetlands during the Late Mesolithic and Middle Neolithic. She does incorporate some new interpretations of vegetation, but the emphasis lies on human use of the landscape and plants.
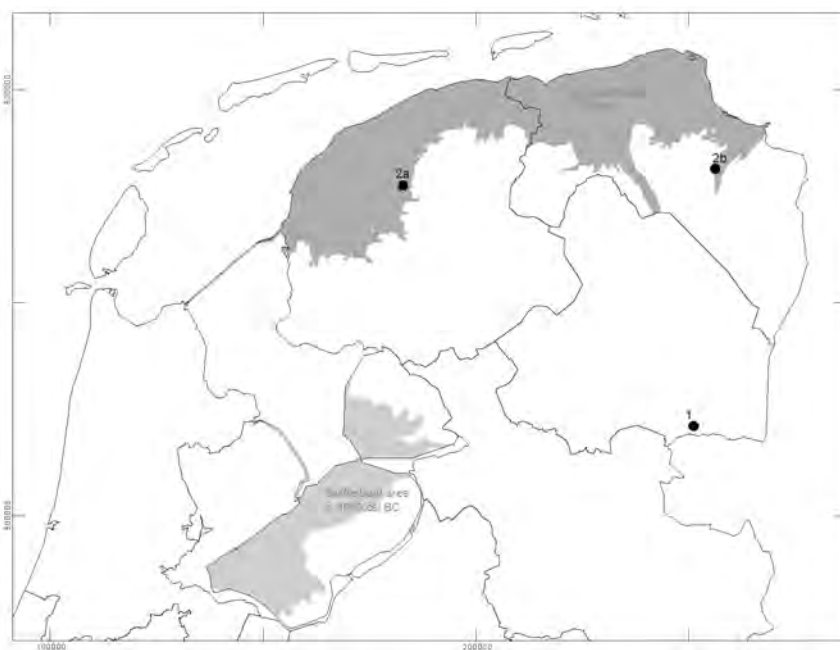
Figure 1.6 Location of the two main research areas in the northern part of the Netherlands. The numbers indicate the town of Coevorden (1), discussed in Box 1, and the villages of Marssum (2a) and Noordbroek (2b), both dealt with in Box 2

Rather than present a broad ecological overview – including its cultural implications for the entire geographical and chronological time span mentioned above – this study focuses on a detailed vegetation reconstruction and the implications of

this reconstruction for the Neolithic occupation and exploitation of a small river system in the present Flevopolder.

The river system is connected to the old river IJssel. The river banks in the area that were occupied in Neolithic times formed partly as a direct result of incidental, probably seasonal, mixing of fresh and saline water. These sediments are part of the Wormer Member within the Formation of Naaldwijk (Schepers and Woltinge in prep.). There are two archaeobotanical studies that focus primarily on the Swifterbant creek system (Casparie *et al.* 1977; Van Zeist and Palfenier-Vegter 1981). Some additional comments based on their work were made by Out (2009a).

Terp region | The tidal marine clay deposits in the northern part of the Netherlands are also part of the Formation of Naaldwijk, but no further subdivision is made in this area (De Mulder *et al.* 2003). The area is characterized by the presence of artificial dwelling mounds, called terps. These terps were predominantly erected on salt marsh ridges or creek banks. A prime difference between the terp region and the Swifterbant creek system is its vastness, stretching from the present Dutch province of Noord-Holland all the way to Denmark.

This study deals with the classic Dutch terp region, which comprises those parts of the present provinces of Friesland and Groningen that were subject to incidental flooding at some time during the later Holocene, leading to the formation of widespread tidal marshes. These include the peat area in the transition zone between the (former) salt marsh and the Pleistocene sand deposits that were never buried under Holocene sediments.

The research history of the area dates back to the 19th century. Numerous overviews of the area's geological and cultural history have been presented, for both the scientific community and the general public (e.g. Bazelmans *et al.* 2009, 2012; Bierma *et al.* 1988; Boersma 1970, 2005; Knol *et al.* 2005; Nieuwhof *et al.* 2013). Several geological studies in the area include a palaeo-ecological component, primarily pollen analysis (Griede 1978; Roeleveld 1974; Schoute 1984). Plant macro-remains from several terps have been studied intensively (e.g. Cappers 1995b, 2008; Cappers *et al.* 2005; Nieuwhof 2012; Van Zeist *et al.* 1987). Two

published botanical overviews of the area exist (Beijerinck 1929; Van Zeist 1974). Renewed interest in the study of terps, starting with the excavations at Englum in 2000, prompted a substantial scientific output (e.g. Bakker 2013; De Langen 2012; Gerrets 2010; Nicolay 2010a; Nicolay and Dijkstra 2008; Nieuwhof 2006b, 2008a, 2012, 2013).

Notes

1 The taxa assigned the prefix b (brackish) or z (saline) in the system presented by Runhaar *et al.* (2004) include no tree species.

An objective method based on assemblages of subfossil plant macro-remains to reconstruct past natural vegetation: a case study at Swifterbant, The Netherlands

Schepers, M.
Scheepens, J.F.
Cappers, R.T.J.
Van Tongeren, O.F.R.
Raemaekers, D.C.M.
Bekker, R.M.

ABSTRACT I We present a new method of identifying past plant communities based on a palaeobotanical dataset. The dataset used as a case study consists of plant macro-remains retrieved from the Neolithic settlement Swifterbant S4, The Netherlands. Taxa were grouped based on their present-day concurrence values. Subsequently, phytosociological analysis was performed on the subfossil taxon groups using the software package PALAEO-ASSOCIA, adjusted for this type of research.

Results show that syntaxonomic knowledge on the concurrence of plant species can be used to reconstruct parts of the past vegetation. We further discuss the theory behind the reconstruction of syntaxa, with special emphasis on actualism.

KEYWORDS I Actualism · ASSOCIA · Phytosociology · Plant macroremains · TURBOVEG · Vegetation reconstruction

INTRODUCTION | The reconstruction of past vegetation in the vicinity of archaeological sites has always been one of the key goals in archaeobotany, giving insight into the conditions and exploitation possibilities of the area for its former inhabitants. In the present study, a new objective method is introduced for identifying past vegetation through phytosociology, the study of plant communities. For an introduction to phytosociology, see Braun-Blanquet (1964). The method applies to natural vegetation and the samples analyzed here were not, strictly speaking, from an archaeological feature. We will therefore refer to the samples as palaeobotanical instead of archaeobotanical.

In the case study presented in this paper, focus lies on the reconstruction of the regional vegetation around the site, for the relatively brief period from 4300 to 4000 cal. B.C., and is based on the analysis of plant macro-remains. The methods presented, however, can also be applied to pollen, wood or, and perhaps preferably, a combination of all data available from the site under study. The methodology presented in this paper shows that reliable vegetation reconstruction based on phytosociology can be achieved, even with palaeobotanical samples representing a mixture of plants from different syntaxa (plant communities defined by phytosociology).

Once palaeobotanical data have been gathered, there are two established approaches for their interpretation towards a reconstruction of past vegetation: the individualistic approach and the assemblage approach, which have both been defined by Birks and Birks (2005, 343) and used for climate reconstruction (see below). These methods heavily rely on the uniformitarian assumption, also called actualism. Actualism can only fully be falsified if pure and complete samples are found, providing insight into the composition of a specific past vegetation type. However, pure and complete samples are rare for both macro-remains and pollen samples. Therefore it is necessary to find ways to divide and characterize taxon sets that clearly show a mixture of several vegetation types, as well as to define missing taxa.

Individualistic approach | The individualistic approach is based on information on the environmental optima and tolerances of a

particular taxon. Abiotic values can be derived, for example, from Ellenberg *et al.* (1991) or Runhaar *et al.* (2004). These individual, taxon-bound values may be used to reconstruct specific abiotic conditions of the environment, such as salinity or moisture avail-ability (Behre 1991; Cappers 1994). By combining different abiotic values, a taxon list can be divided into subsets probably sharing the same habitat. Thus, the individual approach is used as an in-direct way to establish an 'assemblage' (see below) as well as an indication of the variability of habitats in the landscape. This approach is suitable, assuming that the response of taxa to envi-ronmental factors did not change and that the combinations of environmental conditions are comparable between the past and nowadays (i.e. actualism), so that most probably the composition of vegetation did not change very much over time. A disadvantage of using abiotic values is that these are based on field observations of growth locations, but insight in which factors influence the occurrence of a taxon is lacking (Bogaard 2004, 7; Charles *et al.* 1997, 1152). Therefore, Charles *et al.* (1997) and Bogaard (2004) propose using functional attributes (biotic factors) such as leaf life span and root length to reconstruct vegetation types for which one might assume that a modern analogy of a combination of factors influencing the chances of a taxon occurring is lacking: a prime example is arable weed vegetation. Recent studies on his-torical changes in synanthropic vegetation (affected by human activities) confirm that changing land use and lifestyle consider-ably alter such vegetation (Lososova and Simonova 2008).

Assemblage approach | The community and assemblage approach explores the interspecific relationships (plant sociology) of plant taxa occurring tgether (concurring) at a site. The interspecific relationships of plants can be expressed in two different ways.

The first is by means of ecological grouping of taxa. Eco-logical taxon groups can be adopted directly from the literature (Arnolds and Van der Maarel 1979; Ellenberg *et al.* 1991, 71-75; Runhaar *et al.* 2004, 24-26), by adjusting adopted taxon groups to palaeobotanical datasets (Kreuz 2005, 85 [after Ellenberg *et al.* 1991]; Out 2012 [after Arnolds and Van der Maarel 1979]), or they can be constructed manually. Manually means here that the

groups are formed by the individual researcher, based on expert knowledge, for example of the taxon's past or current environment. The ordering of the data in ecological taxon groups is particularly useful in archaeological contexts, where the relationships between human impact and ecology are an important research goal.

Ecological taxon groups such as 'arable weeds' and 'plants of trampled places' may be better suited to archaeological interpretations than possibly related synanthropic vegetation units such as the syntaxa *Veronico-Lamietum hybridi* or *Plantagini-Lolietum perennis*. In contrast to syntaxonomy, where concurrence is based on many actual vegetation descriptions of taxa occurring together, ecological groups have been artificially created by combining plant taxa and environmental characteristics. Concurrence of the taxa in these groups needs not to have been actually witnessed in a real-life situation (Arnolds and Van der Maarel 1979, 305).

The second way to organise taxa is by phytosociology. This approach aims at identifying established plant communities which resulted in the palaeobotanical dataset under study. These plant communities have been empirically defined by mapping present-day vegetation in the field. There are several methods for the identification of syntaxonomical units manually (Van Geel *et al.* 2003; Van Zeist and Palfenier-Vegter 1981). Successful attempts to reconstruct past vegetation by modern analogues are presented in classic studies by Overpeck *et al.* (1985) and Körber-Grohne (1992).

The present study explores the possibility of treating a palaeobotanical sample as a sample of modern vegetation (relevé, or plot), enabling comparisons to the dataset comprising all Dutch relevés to reconstruct former syntaxonomic units (plant communities). By this means, we have an objective way of classifying the past vegetation, supported by a huge amount of comparative data. A comprehensive description of this methodology is presented below. The validity of using present-day syntaxonomy for the reconstruction of past vegetation is further explored in the discussion.

This case study is carried out on drift litter collected in the vicinity of the Neolithic site Swifterbant S4, dated from 4300 to 4000 cal. B.C. (Figs 2.1 and 2.2). There are three major advantages
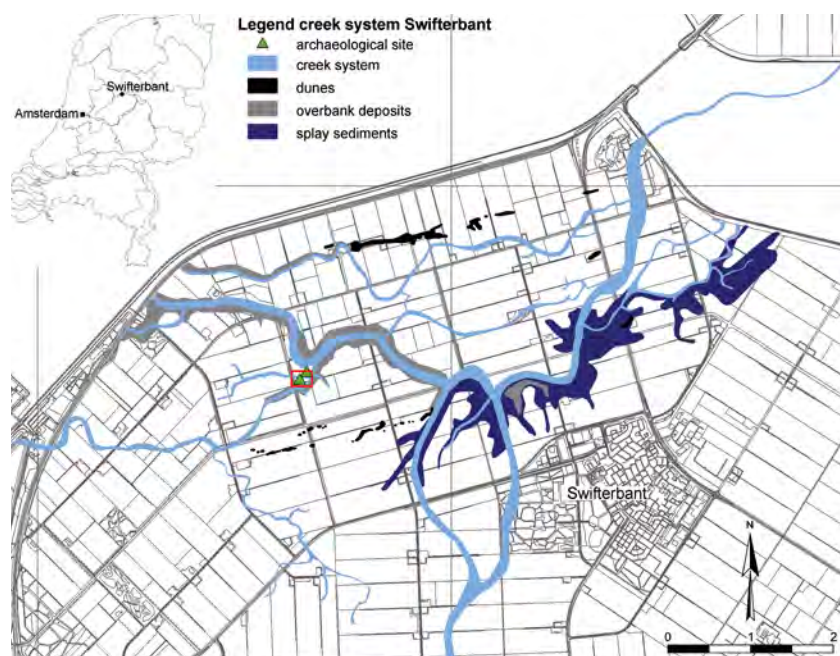
Figure 2.1 The Swifterbant creek system in The Netherlands and the location of the sampling sites mentioned in the text (after Dresscher and Raemaekers 2010, drawing by Erwin Bolhuis)

of using drift litter: (1) a high taxon number can be found within a small sample, which is time-efficient, (2) drift litter is less likely to have been disturbed by direct human activities than samples taken from settlement layers, and (3) most taxa found in drift litter are likely to be of regional origin, thus giving a good indication of the surrounding vegetation (*cf*. Wolters and Bakker 2002, table 4.5).

MATERIALS AND METHODS | Swifterbant site description and sampling |
The Swifterbant Culture consisted of Late Mesolithic hunter-gatherers (c. 5000–4700 cal. B.C.) and Neolithic hunter-gatherer-farmers (c. 4700–3400 cal. B.C.) in the central Netherlands. Overviews of this culture have been published by Raemaekers (1999) and Louwe Kooijmans (2005). The past environment of the Swifterbant region is traditionally characterized as an area of wetland creek systems (Fig. 2.1). This characterization is partly based on a study by Van Zeist and Palfenier-Vegter (1981), who published a vegetation reconstruction of the Swifterbant area using a phy-

tosociological approach on plant macro-remains from soil sam-
ples of settlement layers of the inhabited levee site S3 (Fig. 2.2).
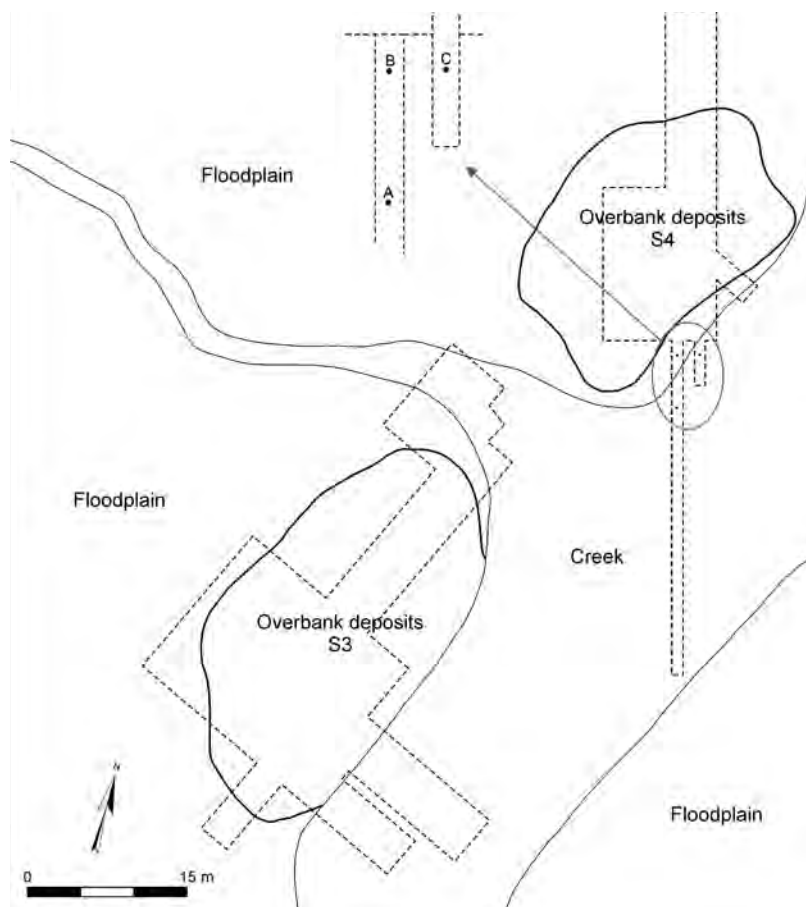
Figure 2.2 Subsection of Figure 2.1 showing the location of the Swifterbant S3 and S4 site (after Deckers *et al.* 1980). All labels refer to geomorphological units (solid lines). The overbank deposits are confined here by the maximum extent of the archaeological sites as determined through both coring and excavation. The dotted lines represent the boundaries of the excavated areas, including the 2006 trench and the location of the samples (drawing by Erwin Bolhuis)

The present study is based on palaeobotanical samples close to the levee site Swifterbant S4, located on the bank of a creek some 30 m northeast from the center of site S3 (50°36 "N 5°34'48 "E; Fig. 2.2). In 2006, a new excavation was carried out here in order to gain a better understanding of the landscape, concentrating on the lev-ee's shoreline and the creek fill, rather than on the levee itself.

During the excavation, an accumulation of drift litter was discovered from which three samples were taken for palaeobotanical analysis (Fig. 2.2). Because of the presence of small amounts of archaeological material in the drift litter, it is dated in the period of habitation of the settlements on the levees, between 4300 and 4000 cal. B.C.

A single sample (sample A) originated from a broad accumulation of drift litter at -6.7 m Normaal Amsterdams Peil (Dutch Ordinance Datum) and two samples (B and C) originated from a single narrow band of drift litter at -6.0 m NAP on the same creek bank. An increasing rise of mean high water levels caused the whole creek system to be covered with clay sediments directly after the period of habitation (Ente 1976; Van de Plassche *et al.* 2005), preventing post-habitational contamination.

The total sample volumes were 11.5, 16 and 26 l for the samples A, B and C, respectively. Samples were wet-sieved using various mesh sizes (4.0, 2.0, 1.0, 0.5 and 0.2 mm) and various volumes of the residues were checked for plant macro-remains with a stereomicroscope. Whereas the 4.0, 2.0 and 1.0 mm fractions were studied completely, smaller representative proportions have been examined of the 0.5 mm (~25 %) and 0.2 mm (<10 %) fractions, until no new taxa were found within a reasonable time. Identification was carried out using the reference collection of the Groningen Institute of Archaeology and the *Digital Seed Atlas of The Netherlands* (Cappers *et al.* 2006). Nomenclature for taxa follows Van der Meijden (2005), for syntaxa Schaminée *et al.* (1995a, 1995c, 1996, 1998) and Stortelder *et al.* (1999).

Primary data analysis I This analysis aims to objectively identify plant communities that grew near the archaeological site. The only taxon omitted from the macro-fossil dataset is *Triticum turgidum* ssp. *dicoccon* (emmer wheat), for it is absent from the reference set of present day Dutch vegetation.

Our three samples were analyzed separately. We only used the presence of species in the samples, because many factors influence the quantitative relationship between standing vegetation and density of plant macro-fossils. The samples were treated as if they were relevés in the process of the identification

analysis. Since we used presence/absence data of the taxa occurring in the three archaeological samples, they are, however, not strictly relevés as these should include relative abundances of taxa. TURBOVEG, a software package for the storage and analysis of relevés (Hennekens and Schaminée 2001), does provide the option of importing relevés on a presence/absence basis, which would then more correctly have to be named 'taxa lists'. These taxa lists were then exported as a Cornell Condensed file (cc!) to be able to import the the data into the analytic software package ASSOCIA (Van Tongeren *et al.* 2008). For our purpose, an extra routine was developed to estimate associations between taxa in modern vegetation, the modified version being called PALAEOASSOCIA. Taxa are considered to be associated if their concurrence is larger than estimated from their separate frequencies under the assumption of independency. For each pair of taxa (A and B) a contingency table was computed from the synoptic syntaxonomic tables (computed from Schaminée *et al.* [1995a, 1995c, 1996, 1998] and Stortelder *et al.* 1999) available in PALAEOASSOCIA. Only syntaxa were considered in which at least one of the subfossil taxa of the sample was present and, because there is no prior knowledge about the area occupied by the syntaxa, all syntaxa were given the same weight. The formulae that calculate the estimates for the probabilities of finding each of the possible four combinations of two taxa are given in Table 2.1.

$p\,(\text{not A not B}) = \dfrac{\Sigma\,f\,(\text{not A not B})}{n}$	$p\,(\text{B not A}) = \dfrac{\Sigma\,f\,(\text{B not A})}{n}$	$p\,(\text{not A}) = 1 - p\,(A) = \dfrac{\Sigma\,f\,(\text{not A})}{n}$
$p\,(\text{A not B}) = \dfrac{\Sigma\,f\,(\text{A not B})}{n}$	$p\,(\text{A and B}) = \dfrac{\Sigma\,f\,(\text{A and B})}{n}$	$p\,(A) = \dfrac{\Sigma\,f\,(A)}{n}$
$p\,(\text{not B}) = 1 - p\,(B) = \dfrac{\Sigma\,f\,(\text{not B})}{n}$	$p\,(B) = \dfrac{\Sigma\,f\,(B)}{n}$	

Table 2.1 Formulae for the estimation of the observed probabilities (present time) of the four possible combinations of species A and B from the synoptic table and their marginal totals; *p* is the probability and *f* is the relative frequency of the species in the syntaxa. The cases are indicated in *parentheses: A (B)* denotes that species *A (B)* is present and *not A (not B)* denotes that species *A (B)* is absent, *n* is the number of vegetation types (syntaxa) considered.

Under the assumption that the taxa are independent, expected probabilities were computed with the formulae in Table 2.2.

$\dot{p}$ (not A not B) = (1 - p(A) $\cdot$ 1 - p(B)	$\dot{p}$ (B not A) = 1 - p(A) x p(B)
$\dot{p}$ (A not B) = p (A) $\cdot$ 1 - p(B)	$\dot{p}$ (A and B) = p (A) x p(B)

Table 2.2 Formulae for the computation of the expected probabilities *(ṗ)* under assumption of independent probabilities

If the frequency (probability) of the combination of both taxa (A and B) as computed in by the formula in Table 2.1 is larger than the value computed in the Table 2.2 formula, the taxa are associated; if this value is smaller, the taxa exclude each other. The logarithm of the ratio between p (A and B) and $\dot{p}$ (A and B) is a symmetric index of association, which is positive for associated taxa, negative for taxa that exclude each other and ca. zero for taxa that are independent. In a spreadsheet, taxon groups were constructed in the taxon-by-taxon association matrix by manually reordering the rows and columns to obtain highly positive values along one diagonal and negative values far away from this diagonal. The manual reordering of taxa was made easier by applying conditional formatting (Table 2.3). The taxon groups were made as extensive as possible to increase the chances of reliably assigning each group to a syntaxon.

The taxon groups were once again imported into TUR-BOVEG, exported as a Cornell Condensed file, and objectively labelled according to their association with a syntaxon using PALAEOASSOCIA. Because the subfossil taxon lists are incomplete, we modified the ASSOCIA routines so that the list of possible syntaxa was based on the weirdness index only (Van Tongeren *et al.* 2008). The weirdness index is calculated as the sum of all contributions to -2ln (likelihood) for the taxa present in the sample. If a taxon is present in a syntaxon, the contribution to the weirdness is low. In the original ASSOCIA package, the degree of association of relevés to syntaxa is also based on the incompleteness index. This is the opposite of the weirdness index, calculated from the sum of all contributions to -2ln (likelihood) for the taxa absent from the sample but present in the association it is compared to. Since all palaeobotanical datasets have missing taxa (Küster 1991, 18), the incompleteness index is not applicable to palaeobotanical datasets.

	CAREPSE	ELEOP-P	SCIRL-T	POLNLAP	ATRPLIT	POLNAVI	SONCASP
CAREPSE	****	-0,01	0,21	-0,04	-0,24	0,17	-0,25
ELEOP-P	-0,01	****	0,58	0,2	-0,21	0,04	0
SCIRL-T	0,21	0,58	****	0,23	-0,08	0,35	-0,04
POLNLAP	-0,04	0,2	0,23	****	0,02	0,46	0,43
ATRPLIT	-0,24	-0,21	-0,08	0,02	****	0,62	0,51
POLNAVI	0,17	0,04	0,35	0,46	0,62	****	1,08
SONCASP	-0,25	0	-0,04	0,43	0,51	1,08	****
ATRPPAT	-0,25	-0,14	-0,01	0,6	0,55	1,48	1,24
POLNPER	-0,12	0,09	-0,07	0,59	0,11	1,29	1,09
CHENALB	-0,3	-0,01	-0,14	0,65	0,27	1,56	1,3
SOLANIG	-0,21	-0,06	-0,06	0,46	0,38	1,21	1,21
RUMEOBT	-0,2	-0,1	-0,09	0,21	-0,02	0,66	0,62
STELMED	-0,29	-0,08	-0,15	0,24	0,27	1,25	0,92
GALE-SP	-0,04	-0,27	-0,22	0,11	0,18	0,58	0,56
GALU-SP	0,34	-0,31	-0,28	0,15	0,08	0,03	0,07
MALUSYL	-0,23	-0,45	-0,68	-0,04	0,28	-0,06	0,26
LOLI-SP	-0,26	-0,37	-0,33	-0,08	0,23	0,2	0,21
CARUCRI	-0,46	-0,29	-0,42	0,19	-0,05	0,73	0,82
GALETET	-0,2	-0,54	-0,55	-0,36	-0,2	0,25	0,05
ANTISYL	-0,15	-0,36	-0,17	0,44	-0,28	-0,24	0,26
URTIDIO	-0,28	-0,42	-0,42	-0,32	-0,37	-0,11	0,33
CONIMAC	-0,36	-0,73	-1,1	-0,87	-0,35	-0,29	0,44
CORLAVE	-0,54	-0,73	-0,84	-0,31	-0,16	-0,67	-0,13

Table 2.3 Section of the sample B association matrix. Green: strong association. Yellow: medium association. White: weak association. Red: negative association. For species codes on x and y axis, see Appendix 2A

Reduction of possible vegetation types | The obtained list of possible vegetation types was further constrained by three factors:

First, a threshold was set for each taxon group, based on how much a suggested vegetation type may differ from the type with the lowest weirdness value (first suggestion). The threshold was calculated by adding the squared number of taxa in the group divided by 20, this latter value being arbitrary, based on the observation that few groups include more than 20 taxa, to the weirdness value of the first syntaxon suggested. This threshold was lower for taxon-poor groups, which tend to produce longer lists of syntaxa. All syntaxa for which the weirdness value exceeded the threshold were rejected.

Second, we chose not to accept basal or derivative communities, because these in particular are greatly influenced by

ATRPPAT	POLNPER	CHENALB	SOLANIG	RUMEOBT	STELMED	GALE-SP
-0,25	-0,12	-0,3	-0,21	-0,2	-0,29	-0,04
-0,14	0,09	-0,01	-0,06	-0,1	-0,08	-0,27
-0,01	-0,07	-0,14	-0,06	-0,09	-0,15	-0,22
0,6	0,59	0,65	0,46	0,21	0,24	0,11
0,55	0,11	0,27	0,38	-0,02	0,27	0,18
1,48	1,29	1,56	1,21	0,66	1,25	0,58
1,24	1,09	1,3	1,21	0,62	0,92	0,56
****	1,21	1,56	1,21	0,66	1,15	0,63
1,21	****	1,55	1,4	0,65	1,13	0,46
1,56	1,55	****	1,56	0,84	1,33	0,7
1,21	1,4	1,56	****	0,6	1,12	0,53
0,66	0,65	0,84	0,6	****	0,64	0,4
1,15	1,13	1,33	1,12	0,64	****	0,51
0,63	0,46	0,7	0,53	0,4	0,51	****
0,02	0,05	0,01	0,07	0,12	0,06	0,23
0,19	0,09	0,11	0,13	0,29	0,21	0,25
0,21	0,09	0,17	0,15	0,29	0,26	0,22
0,92	0,6	1,01	0,73	0,93	0,63	0,6
0,29	0,39	0,44	0,35	0,3	0,5	0,2
0,07	-0,19	-0,08	0,07	0,81	0,36	0,3
0,23	0,06	0,21	0,19	0,69	0,39	0,36
0,21	0,01	0,36	0,37	0,59	0,21	0,43
-0,42	-0,13	-0,17	0,2	0,35	0,17	0,26

human actions (Kopecký and Hejný 1974). Since human influence nowadays differs greatly from that in prehistoric situations, these communities cannot be compared.

Third, the suggested vegetation types were studied in more detail through the PALAEOASSOCIA diagnosis file. This file shows to what extent the taxa in a group fit a suggested syntaxon, and which taxa are normally present in that syntaxon but were missing here. Taxa listed in over 95 % of present-day relevés of a syntaxon but absent from the subfossil taxon group were reconsidered more closely. The probability of not finding these taxa in palaeobotanical analyses was roughly estimated by comparing the frequency of the reported recordings of such a taxon in the Groningen reference database as well as the Dutch database of palaeobotanical plant macro-remains RADAR (version 2006, listing 6,546 samples with 131,879 records of 3,552 taxa; for introduction in RADAR, see Van Haaster and Brinkkemper 1995). If an absent taxon is known to be rarely, if ever, found in archaeological

samples due to, unlikelihood of preservation, it might be considered to have occurred in the past landscape as a plausible addition to the taxa found in our samples. However, if a taxon is often found in palaeobotanical samples, its absence in our study is more significant and therefore we consider the probability that such a vegetation type had been present in our study area to be low.

On the other hand, if a taxon is present in less than 5 % of present-day relevés of a syntaxon but was found in the subfossil sample, the suggested vegetation type was considered unlikely to have been present and therefore excluded. Taxa only identified at the genus level were ignored in this step of the analysis, as the PALAEOASSOCIA program considers every taxon a separate 'entity'. It recognizes no taxonomical relationship between species within the same genus and between a species and the genus it belongs to. All taxa identified up to the genus level in the archaeological sample occur in most present-day relevés only at the species level and will therefore always appear as 'weird'.

This resulted in a limited list of syntaxa for each group of taxa within each subfossil sample. The combined list of syntaxa for the three subfossil samples can be used for the historic vegetation reconstruction of the vicinity of the study site. This reconstruction will be presented in another paper, by combining the syntaxonomic information with geographic information of the landscape.

RESULTS | The taxon lists of the three subfossil samples (n=47, 37 and 35; Appendix 2A) show a high variation in habitat types, ranging from half-moist to aquatic, and both fresh and salt water. Samples A, B, and C were split into 9, 13, and 11 overlapping groups, respectively (Appendices 2B-2D). By making overlapping rather than exclusive taxon groups, we avoid restricting subfossil taxa to only one specific community (Küster 1991, 19). The groups were identified using PALAEOASSOCIA. Syntaxon codes (such as 29Aa2b) are built up hierarchically: the first two positions indicate the class, the following capital letter indicates the order, the following letter the alliance and the last number the association. An occasionally present last letter indicates a subassociation. This means that the syntaxon chosen as an

example here is in class 29 *(Bidentetea tripartitae)*, order A *(Bidentetalia tripartitae)*, alliance a *(Bidention tripartitae)*, association 2 *(Rumicetum maritimi)* and subassociation b *(R. maritimi chenopodietosum)*.

The number of suggested syntaxa is negatively related to the number of taxa in a taxon group: the more taxa in a group, the lower the number of suggested syntaxa. The number of suggested syntaxa ranges from 2 to 28. Appendix 2E shows the syntaxa initially suggested for the taxon groups in sample A. First, all syntaxa were excluded that exceeded the threshold difference with the most likely syntaxon; Table 2.4 shows the thresholds for sample A. Subsequently all basal and derivative communities were excluded. The number of remaining syntaxa ranges from 1 to 8 (Table 2.5). The reduced lists for the three samples can be divided into three networks: wet communities, pioneer communities, and woodland communities. These groups are visualized for sample A in Figures 2.3, 2.4 and 2.5.

The remaining syntaxa were studied in more detail using the PALAEOASSOCIA extended diagnosis file, which led to further exclusion of syntaxa as shown in Table 2.5. A complete description of the decisions leading to this further reduction would stretch too far; a few examples will be discussed here.

Sample A	1	2	3	4	5	6	7	8	9
# taxa	15	14	15	17	18	22	21	17	17
# taxa/20	0,8	0,7	0,8	0,9	0,9	1,1	1,1	0,9	0,9
# taxa / (20 * # taxa)	11,3	9,8	11,3	14,5	16,2	24,2	22,1	14,5	14,5
lowest weirdness	60	118	105	96	76	124	144	127	123
threshold	71,6	127,9	116,2	110,3	92,5	147,9	166,3	141,2	137,3

Table 2.4 Calculation of threshold values for sample A. # taxa = number of taxa. The top row represents the taxon groups as presented in Appendix 2B. The threshold leads to an exclusion of suggested syntaxa differing too much from the first suggested syntaxon, as visualised in Appendix 2E

In taxon group 8 of sample B, syntaxon 31Ab1b *(Urtico-Malvetum typicum)* is among the suggested vegetation types. *Urtica urens* is present in over 95 % of the relevés of this type. As this species is well recognized and often found in palaeobotanical samples, its absence here makes the former presence of this syntaxon highly
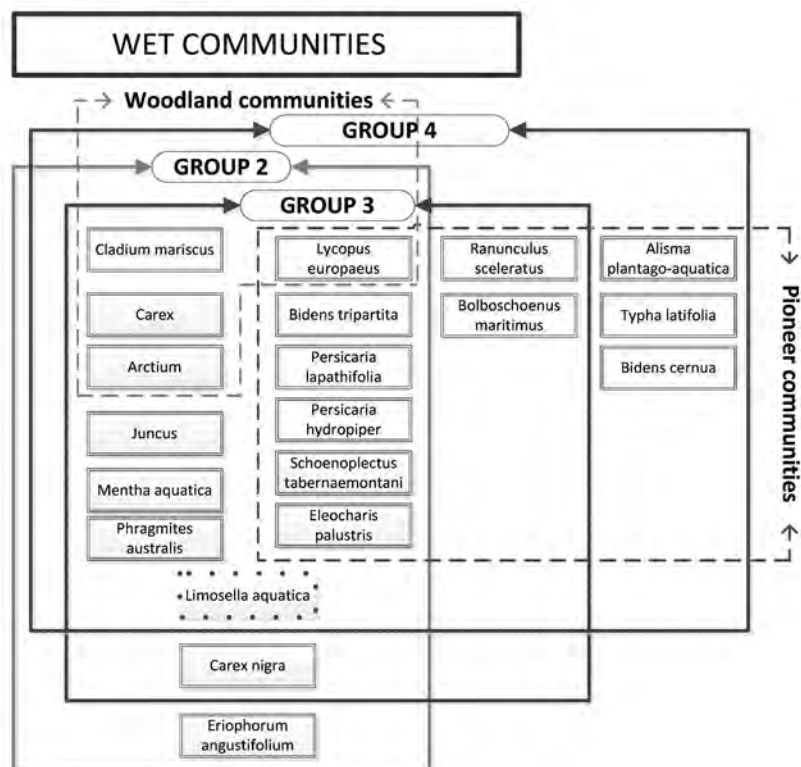
Figure 2.3 The taxon groups dominantly representing wet communities from sample A. The species with the dotted frame *(L. aquatica)* is a suggested species

unlikely. In the same line of reasoning, vegetation type 37Ac5 (*Orchio-Cornetum*) could be excluded as a possibility for group 11 of sample C. This vegetation type should have contained *Cornus sanguinea* which is an easily identifiable and frequently found species.

For the suggested vegetation type 31Ab2c in group 7 of sample B however, we acknowledge the possibility that the absence of *Hordeum murinum* may be related to its palaeobotanical invisibility, rather than to factual absence. In Dutch research, no findings of this species prior to 800 B.C. have been recorded. The former presence of this syntaxon could therefore not be excluded, so *H. murinum* is considered a 'suggested species'. The comparison with present-day plant communities also provides the possibility of suggesting the presence of species not found
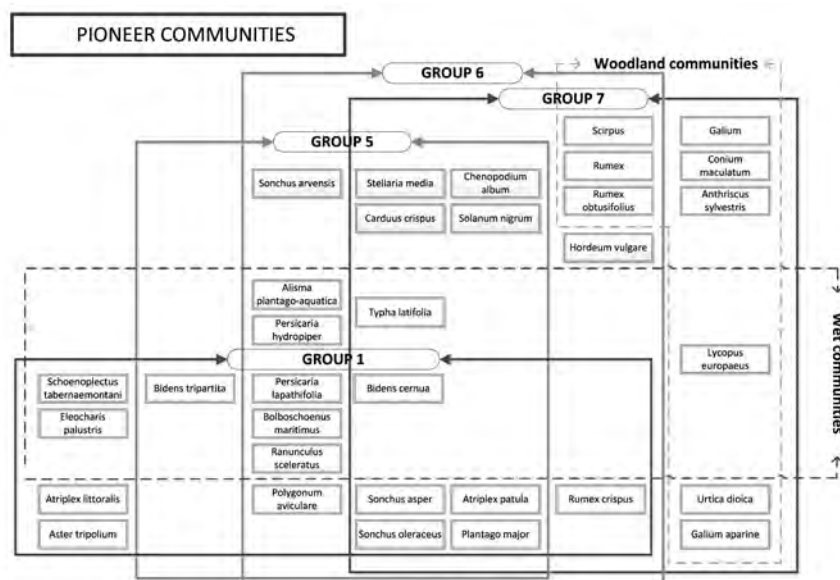
Figure 2.4 The taxon groups dominantly representing pioneer communities from sample A

in the samples. Another good example of a 'suggested species' is *Limosella aquatica*. In vegetation type 29Aa4, suggested for groups 2-4 in sample A (Fig. 2.3) and group 3 in sample C, this species is present nowadays. Though it is not found in the drift litter samples, it has been identified previously in the Netherlands in low numbers in palaeobotanical samples.

Additionally, some taxa are considered 'weird species' in most of the cases. For example, *Hordeum vulgare* (barley) and *Malus sylvestris* (crab apple) are considered weird, though their occurrence is not impossible in some of the suggested vegetation types. Human activity in the vicinity of these sites may very well have played a role for these useful plants.

The vegetation types suggested for the three subfossil samples are summarized in Table 2.6. We emphasize that many are very closely related and likely to be found within a relatively short distance of each other in tidal landscapes. They may even occur along a gradient or in succession. This is supported by the observation that the association matrix shows substantial overlap in the taxon groups, suggesting a *limes divergens* (Westhoff and Van der Maarel 1978, 303-305).
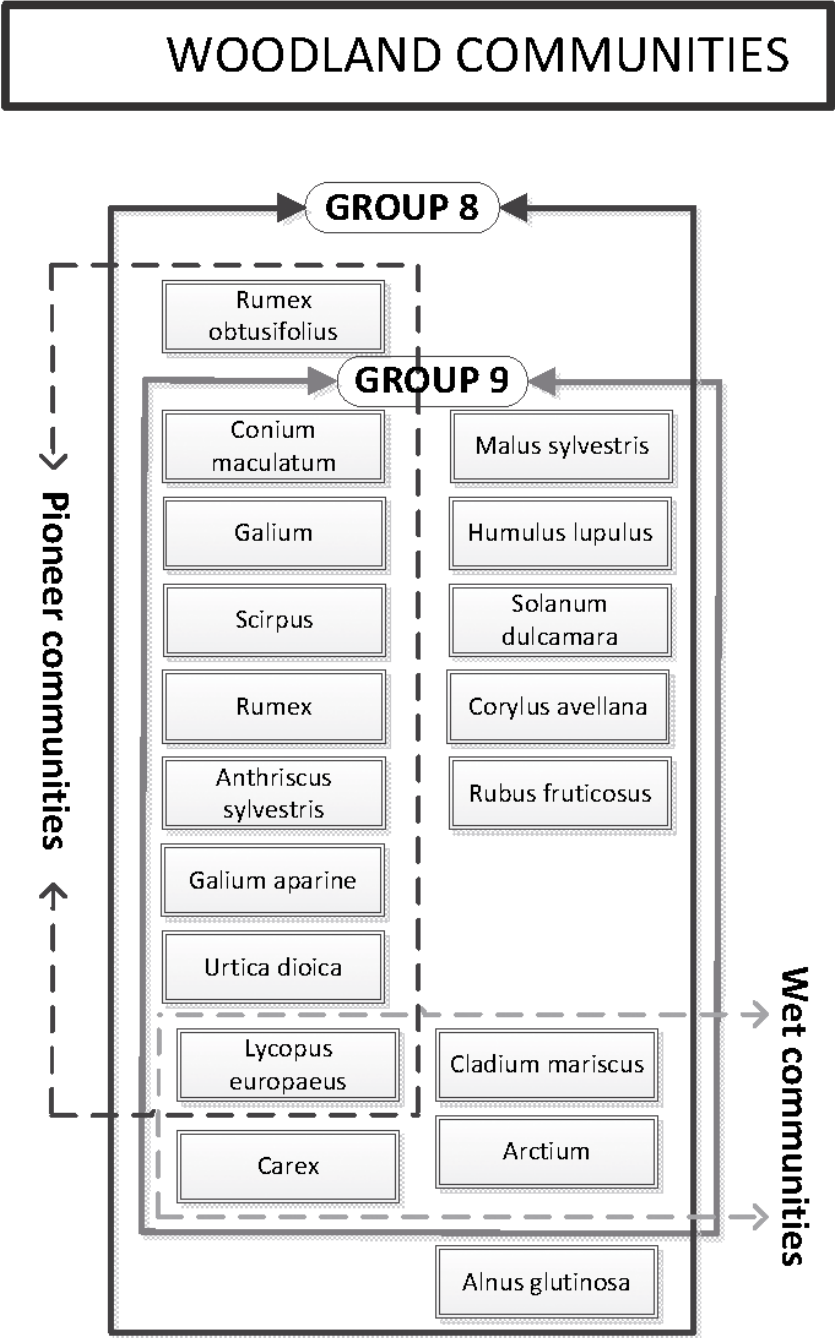
Figure 2.5 The taxon groups dominantly representing woodland communities from sample A

DISCUSSION | By treating three palaeobotanical samples from a drift litter accumulation near a Neolithic settlement as present-day vegetation recordings on a presence/absence-level, we were able to compare them with an extensive set of modern Dutch phytosociological data. Using these data, we split the subfossil samples, which are clearly a mixture of several vegetation types, into a number of groups of taxa likely to concur. Concurrence networks have recently been used by Araújo *et al.* (2011) in studies on climate. For the taxon groups that we created, we identified the most similar plant association(s) described by Schaminée *et al.* (1995a, 1995c, 1996, 1998) and Stortelder *et al.* (1999) via the analytic software package associa (Van Tongeren *et al.* 2008). The results of the three samples are consistent with one another and fit in well with existing knowledge on the geological and hydrological conditions of the prehistoric region.

Data analysis | We chose to use presence/absence because of the large discrepancy between the relative abundance of plant macro-remains compared to relative abundance of plant species in present-day recordings. Direct translations of seed counts into relative plant abundance as performed by Körber-Grohne (1979) are hampered by both archaeological and ecological problems (Bekker *et al.* 2000; Van Zeist and Palfenier-Vegter 1981, 133–134).

For instance, seed production has a high interspecific variability, but is also influenced at the intraspecific level by such factors as differences in reproductive allocation and effort (Bazzaz *et al.* 1992), pollination failure (Fenner 1985) and pre-dispersal seed predation (Crawley 1992). Also, seed dispersal potential has a high interspecific variability, resulting in patterns that deviate quantitatively from the standing vegetation. Seed dispersal potential is also a possible cause for qualitative dissimilarities between seed bank and vegetation: dispersal may result in the loss of taxa from the seed bank, whereas it may also result in the presence of taxa in the seed bank that are not members of the standing vegetation. Thompson and Grime (1979) showed a lack of general correspondence between taxon composition of the seed bank and the associated vegetation. More recently, Bekker *et al.* (2000) found Czekanowski similarity indices (quantitative

A

1	2	3	4	5	6	7	8	9
29Aa3a	16Ab4a	08Aa2	08Aa2	29Aa3c	29Aa3c	29Aa3c	43Aa5	43Aa5
29Aa2b	08Aa2	29Aa2b	29Aa2b	29Aa2b	29Aa3b	29Aa3b		
	06Ac1	29Aa4	29Aa4	29Aa3b	29Aa2b	31Ab3c		
	29Aa4							
	29Aa2b							
	08Bc2b							

B

1	2	3	4	5	6	7	8	9	10	11	12	13
12Ba02	08Bd1	08Bd1	29Aa3a	29Aa2b	29Aa3b	31Ab2c	31Ca1b	31Ab3a	31Ab3c	31Ab3c	31Ab3a	43Aa5
08Bb2	06Ac4	08Bc2b		29Aa3c	29Aa2b	31Ca1b	31Ab3c	31Ab3c			37Ab1a	43Aa1a
29Aa3a	06Bc01	08Bb02		29Aa3b		31Ab3c	31Ab3a	31Ca1b			43Aa1a	37Ab1a
		06Ac4		29Aa3a			30Bb1b				43Aa5	
							31Ab2c				43Aa1b	
							31Ab1b				31Ab3c	
							30Ab3				37Ab1c	
							31Aa2b					

C

1	2	3	4	5	6	7	8	9	10	11
08Aa2	06Ac4	29Aa2b	08Aa2	29Aa2b	29Aa3c	29Aa3c	29Aa3c	31Ab3a	37Ab1c	43Aa5
08Aa1	12Ba2C	29Aa4	29Aa2b		29Aa2b	29Aa2b			31Ab3a	43Ab1b
									34Aa1c	37Ac5
									43Aa5	43Aa4
									34Aa1b	
									37Ab1a	

Table 2.5 Suggested syntaxa codes for all samples of macro-remains (A, B, C) after reduction by threshold value and removal of basal and derivative communities showing further reduction by a closer examination of the palaeoassocia diagnosis file (crossed out). The top row for all three samples represents the taxon groups as presented in appendices 2B-2D. The color scheme follows the field guide of Dutch plant communities (Schaminée *et al.* 2010). Blue: open water and marshes. Light green: Grasslands and heathland. Orange: Coastal and inland pioneer communities. Dark green: rough, thicket and woodlands

Sörensen index) of 40–60% between quantitative soil seed bank and vegetation data from dry and wet semi-natural grasslands, indicating that a high deviation of seed bank and vegetation composition is not uncommon. These deviations at both the quantitative and qualitative level hamper fine-scale vegetation

reconstruction (Cappers 1995a). An additional problem is that accumulated drift litter is not a seed bank. Drift litters along big rivers and on seashores are especially likely to contain plant remains originating from vast areas both in space and time (Cappers 1993). A quantitative translation of our seed numbers into standing vegetation would require extensive studies on the relationship between species composition in an area and the accumulation of their remains in drift litters (Moore 1986, 545). Such studies have been performed by Holyoak (1984) and Wolters and Bakker (2002). However, to make such a study applicable to our dataset, it would have to be carried out in an area comparable to the area under study, which would inevitably require some circular reasoning.

Synt.code	A	B	C	Total	Syntaxon
06Ac4			1	1	Samolo-Littorelletum
08Aa2	3		2	5	Polygono-Veronicetum anagallidis-aquaticae
08Bb2		1		1	Scirpetum tabernaemontani
08Bc2b	1	1		2	Caricetum gracilis comaretosum
08Bd1		2		2	Cladietum marisci
16Ab4a	1			1	Ranunculo-Senecionetum juncetosum articulati
29Aa2b	6	2	5	13	Rumicetum maritimi chenopodietosum
29Aa3a	1	2		3	Chenopodietum rubri spergularietosum
29Aa3b	3	2		5	Chenopodietum rubri inops
29Aa4	3		1	4	Eleocharito acicularis-Limoselletum
30Ab3		1		1	Chenopodio-Oxalidetum fontanae
30Bb1b		1		1	Spergulo arvensis-Chrysanthemetum euphorbietosum
31Aa2b		1		1	Erigeronto-Lactucetum erysimetosum
31Ab2c		2		2	Hordeetum murini arctietosum
31Ab3a		2	2	4	Balloto-Arctietum typicum
31Ab3c	1	6		7	Balloto-Arctietum verbascetosum
31Ca1b		3		3	Echio-Melilotetum
34Aa1b			1	1	Senecioni-Epilobietum ceratocapnetosum
34Aa1c			1	1	Senecioni-Epilobietum inops
37Ab1a		2	1	3	Pruno-Crataegetum typicum
43Aa1a		2		2	Violo odoratae-Ulmetum allietosum

43Aa4		1	1	Carici remotae-Fraxinetum
43Aa5	2	1	3	Pruno-Fraxinetum
43Ab1b		1	1	Stellario-Carpinetum orchietosum

Table 2.6 Summary of the suggested syntaxa for all samples. The color scheme follows the field guide of Dutch plant communities (Schaminée *et al.* 2010). The numbers indicate how often the syntaxa have been suggested (see Table 5). Blue: open water and marshes. Light green: Grasslands and heathland. Orange: Coastal and inland pioneer communities. Dark green: rough, thicket and woodlands

Furthermore, a direct translation of the seed numbers of our mixed assemblage into standing vegetation would neglect the fact that some taxa may concur in more than one of the suggested vegetation types, but in different ratios. Our methodology makes it possible to first identify a particular plant community, and then use other knowledge of the local landscape (such as geomorphology and soil characteristics) to estimate the location and relative abundance of that community in the region.

The methodology used to divide the association matrix into overlapping taxon groups is time consuming. An alternative and much faster way would be to cluster the taxa in the association matrix, treating it as a similarity matrix. However, the hierarchical level at which the clustering should be defined and the problem of ordering the clusters in a non-hierarchical network would still have to be solved.

Actualism I There are two ways in which a plant community that occurred in the region in the past may not have been identified. First, too few taxa of the plant community have been found as fossils. Second, plant species concurrence may have changed since prehistoric times, resulting in non-analogue plant communities. The hypothetical presence of an unrecognized community that does have a present-day analogue should be considered a form of a false negative (Jackson and Williams 2004). Although they defined this term for a whole dataset of pollen (seemingly) lacking a modern analogue, it also applies to the current study's methodology.

Our analysis is based on actualism, which applies to both the individualistic and the assemblage approach (Birks and Birks 2005, 343). Actualism assumes that characteristics

of species and/or interspecific concurrence did not change over time. However, differences in plant sociology may actually occur when either taxa evolve or when abiotic conditions change into previously absent conditions. The likeliness of this assumption being valid decreases as the distance in time increases (Behre and Jacomet 1991, 83; Gee and Giller 1991). The ecological preferences and tolerances of species are likely to have evolved only marginally in the time span the present paper is dealing with (Behre and Jacomet 1991; Cappers 1995b; Willemsen *et al.* 1996).

A combination of abiotic conditions in the past lacking a modern-day analogue can occur naturally or because of changes in human activity. In the earlier Holocene, natural conditions may have caused non-analogue habitats (Caseldine and Pardoe 1994; Gee and Giller 1991; Kalis *et al.* 2006; Overpeck *et al.* 1985). Several scholars suggest, however, that climatic conditions were roughly stable during the Holocene, especially during its second half (Oldfield 2005). In the period under study here (c. 4300–4000 cal. B.C.), this should therefore not be problematic. The uniformity of climatic conditions is supported by the observation that no taxa currently absent from the Dutch flora were found. Slight alterations in the characteristics of species play a smaller role on the community level, due to the smoothing-out of these differences as the number of taxa increases.

Ecological taxon groups or plant communities which were influenced by human activities may have changed considerably over time. This applies especially to arable weed floras due to changes in farming practices (Hillman 1991; Marshall and Hopkins 1990; Willerding 1979) and to cultivation in ecosystems that are not used for that purpose now. For example, cultivation of salt-marsh areas may have resulted in the inclusion of halophytes in weed associations (Van Zeist 1974, 343). Therefore, syntaxonomy is less suitable for studies focusing on plant husbandry rather than vegetation reconstruction (Bogaard 2004, 5-6).

Following Van Zeist's (1974, 343) line of reasoning that arable weed assemblages will at least partly be a subset of the locally present 'wild' vegetation, an area-specific weed assemblage for this region may be expected to be a subset of the plants in taxon groups assigned to pioneer communities. The associa-

tion matrices show that *H. vulgare* (barley) need not be a weird species within this dataset, but caution needs to be taken with cultivated plants because of the different ecological tolerances of present-day cultivars. Nevertheless, there is ongoing debate whether cereal cultivation took place here locally or not (Cappers and Raemaekers 2008; Out 2008, 2009b; Weijdema *et al*. 2011). It is beyond the scope of this paper to join this debate.

Wider geographic applicability | The methodology presented in this paper is useful for palaeobotanical studies in two ways. In the first stage, it provides an objective method to subdivide a plant list that clearly represents a mixture of vegetation types into sets of taxa that might have grown together in various vegetation types. The created taxon groups will overlap, which is to be expected in a natural landscape with many plant communities. Secondly, these groups can be identified phytosociologically. The methodology can be applied in every region for which synoptic tables of vegetation types are available, preferably containing all taxa retrieved in the palaeobotanical sample(s). For the non-palaeo version of the ASSOCIA package, available as a built-in identification tool in TURBOVEG for Dutch vegetation, a dataset of Czech grasslands has already been used to test its applicability in non-Dutch regions (Van Tongeren *et al*. 2008).

The synoptic tables to be used as a reference set should preferably originate from a region as nearby as possible to the region under study. This also applies to studies using Ellenberg *et al*. (1991) indicator values or other individual characteristics of taxa. Studies on the wider geographic applicability of Ellenberg indicator values have confirmed that the values originally defined for central Europe can also be applied to western and northern Europe (Godefroid and Dana 2007, and references therein), which is an indication that the Dutch reference set can be used in parts of neighbouring countries where no species are present which are absent from The Netherlands.

In regions that differ botanically from The Netherlands, other plant associations will have been defined, although both German and British overviews of plant communities contain

most of our identified syntaxa (or synonyms) at least up to the alliance level (Pott 1992 for Germany; Rodwell 1998a, 1998b, 1998c, 1998d, 2000 for Great Britain).

CONCLUDING REMARKS I The analysis presented in this paper made it possible to reconstruct past vegetation consisting of the main components of wet, pioneer, and woodland syntaxa. Our new method will make it possible to gain insight in hydrology, geomorphology and soil characteristics in regions where they have not been so well preserved as at Swifterbant. The syntaxa within the *Bidention tripartitae* alliance, occurring on periodically flooded, fresh to brackish clay or clayey peat along creeks and ditches, seem to fit in nicely with the geological knowledge of the region (Schaminée *et al*. 2010, 302–305). A further analysis of the results is in preparation, including the position of the syntaxa in the landscape and the implications of the vegetation reconstruction for the use of plant resources by man. Although an exact match to the prehistoric situation can never be claimed, the use of factual plant communities as an analogue opens the way to use parameters of these communities such as biomass production and nutritional value, and also to create realistic reconstructions of the past landscape. This is of great value for the presentation of palaeobotanical information to archaeologists and to the general public.

APPENDICES TO CHAPTER 2

Scientific name	A	B	C	Code
Atriplex patula	1	1	1	ATRPPAT
Bolboschoenus maritimus	1	1	1	SCIRMAR
Chenopodium album	1	1	1	CHENALB
Cladium mariscus	1	1	1	CLAIMAR
Conium maculatum	1	1	1	CONIMAC
Corylus avellana	1	1	1	CORLAVE
Eleocharis palustris	1	1	1	ELEOP-P
Eriophorum angustifolium	1	1	1	ARIOANG
Galium	1	1	1	GALU-SP
Humulus lupulus	1	1	1	HUMULUP
Malus sylvestris	1	1	1	MALUSYL
Mentha aquatica	1	1	1	MENTAQU
Persicaria lapathifolia	1	1	1	POLNLAP
Phragmites australis	1	1	1	PHRAAUS
Polygonum aviculare	1	1	1	POLNAVI
Rumex obtusifolius	1	1	1	RUMEOBT
Schoenoplectus tabernaemontani	1	1	1	SCIRL-T
Solanum dulcamara	1	1	1	SOLADUL
Solanum nigrum	1	1	1	SOLANIG
Sonchus asper	1	1	1	SONCASP
Stellaria media	1	1	1	STELMED
Urtica dioica	1	1	1	URTIDIO
Alnus glutinosa	1	1		ALNUGLU
Anthriscus sylvestris	1	1		ANTISYL
Arctium	1	1		ARCT-SP
Aster tripolium	1	1		ASTETRI
Atriplex littoralis	1	1		ATRPLIT
Carduus crispus	1	1		CARUCRI
Hordeum vulgare	1		1	HOREVUL
Juncus	1		1	JUNC-SP
Persicaria hydropiper	1		1	POLNHYD
Ranunculus sceleratus	1		1	RANUSCE

Rubus fruticosus	1		1	RUBUFRU
Typha latifolia	1		1	TYPHLAT
Galeopsis tetrahit		1	1	GALETET
Juncus gerardi		1	1	JUNGER
Persicaria maculosa		1	1	POLNPER
Alisma plantago-aquatica	1			ALISPLA
Bidens cernua	1			BIDECER
Bidens tripartita	1			BIDETRI
Carex	1			CARE-SP
Carex nigra	1			CARENIG
Galium aparine	1			GALUAPA
Lycopus europaeus	1			LYCPEUR
Plantago major	1			PLAAMAJ
Rumex	1			RUME-SP
Rumex crispus	1			RUMECRI
Scirpus	1			SCIR-SP
Sonchus arvensis	1			SONCARV
Sonchus oleraceus	1			SONCOLE
Alisma		1		ALIS-SP
Carex paniculata		1		CAREPAC
Carex pseudocyperus		1		CAREPSE
Galeopsis		1		GALE-SP
Lolium		1		LOLI-SP
Triticum turgidum ssp. dicoccon		1		n/a
Crataegus monogyna			1	CRATMON
Erica tetralix			1	ERICTET
Ruppia maritima			1	RUPPMAR
Veronica anagallis-aquatica			1	VEROANA
Total N = 60	**47**	**37**	**35**	

Appendix 2A Presence of plant taxa in the samples. The table is arranged according to the samples in which a taxon occurs, in the following order: ABC, AB, AC, BC, A, B, C. The taxon codes are used in the association matrix (Table 2.3)

Taxon \ taxon group number	1	2	3	4	5	6	7	8	9
Aster tripolium	1								
Atriplex littoralis	1								
Eriophorum angustifolium		1							
Carex nigra		1	1						
Arctium species		1	1	1				1	1
Carex species		1	1	1				1	1
Phragmites australis		1	1	1					
Mentha aquatica		1	1	1					
Juncus species		1	1	1					
Eleocharis palustris	1	1	1	1					
Schoenoplectus tabernaemontani	1	1	1	1					
Bidens tripartita	1	1	1	1	1				
Persicaria lapathifolia	1	1	1	1	1	1			
Persicaria hydropiper		1	1	1	1	1			
Bolboschoenus maritimus	1		1	1	1	1			
Alisma plantago-aquatica				1	1	1			
Sonchus arvensis					1	1			
Ranunculus sceleratus	1		1	1	1	1			
Plantago major	1				1	1	1		
Polygonum aviculare	1				1	1			
Atriplex patula	1				1	1	1		
Solanum nigrum					1	1	1		
Stellaria media					1	1	1		
Sonchus asper	1				1	1	1		
Sonchus oleraceus	1				1	1	1		
Chenopodium album					1	1	1		
Bidens cernua	1			1	1	1	1		
Typha latifolia				1	1	1	1		
Carduus crispus					1	1	1		
Hordeum vulgare						1	1		
Rumex crispus	1					1	1		
Rumex obtusifolius						1	1	1	
Rumex species						1	1	1	1

Taxon						
Scirpus species				1	1	1	1
Conium maculatum					1	1	1
Anthriscus sylvestris					1	1	1
Galium species					1	1	1
Urtica dioica					1	1	1
Galium aparine					1	1	1
Lycopus europaeus	1	1	1		1	1	1
Malus sylvestris						1	1
Corylus avellana						1	1
Humulus lupulus						1	1
Solanum dulcamara						1	1
Alnus glutinosa							1
Rubus fruticosus ag.						1	1
Cladium mariscus	1	1	1			1	1

Appendix 2B Overlapping taxon groups of sample A

Taxon \ taxon group number	1	2	3	4	5	6	7	8	9	10	11	12	13
Bolboschoenus maritimus	1				1	1							
Aster tripolium	1			1									
Alisma species	1	1											
Eriophorum angustifolium		1	1										
Mentha aquatica		1	1										
Phragmites australis	1	1	1										
Juncus gerardi	1	1	1	1									
Carex pseudocyperus		1	1	1									
Eleocharis palustris	1	1	1	1	1								
Schoenoplectus tabernaemontani	1	1	1	1	1	1							
Persicaria lapthifolia			1	1	1	1	1						
Atriplex littoralis				1	1	1	1	1					
Polygonum aviculare				1	1	1	1	1	1				
Sonchus asper				1	1	1	1	1	1	1			

Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13
Atriplex patula					1	1	1	1	1	1			
Persicaria maculosa					1	1	1	1	1	1	1		
Chenopodium album					1	1	1	1	1	1	1		
Solanum nigrum					1	1	1	1	1	1	1	1	
Rumex obtusifolius					1	1	1	1	1	1	1	1	
Stellaria media					1	1	1	1	1	1	1	1	1
Galium species						1	1	1	1	1	1	1	1
Malus sylvestris							1	1	1	1	1	1	1
Lolium species							1	1	1	1	1	1	1
Galeopsis species							1	1	1	1	1	1	1
Carduus crispus							1	1	1	1	1	1	1
Galeopsis tetrahit								1	1	1	1	1	1
Anthriscus sylvestris									1	1	1	1	1
Urtica dioica									1	1	1	1	1
Conium maculatum										1	1	1	1
Carex paniculata											1	1	1
Cladium mariscus	1	1	1	1							1	1	1
Arctium species		1	1									1	1
Solanum dulcamara		1	1									1	1
Humulus lupulus												1	1
Corylus avellana												1	1
Alnus glutinosa													1

Appendix 2C Overlapping taxon groups of sample B

Taxon \ taxon group number	1	2	3	4	5	6	7	8	9	10	11
Ruppia maritima	1										
Eriophorum angustifolium		1									1
Juncus gerardi		1	1								
Phragmites australis	1	1	1	1							
Persicaria lapathifolia		1	1	1		1					
Juncus species	1	1	1	1							

Taxon											
Mentha aquatica	1	1	1	1							
Schoenoplectus tabernaemontani	1	1	1	1	1						
Eleocharis palustris	1	1	1	1	1						
Bolboschoenus maritimus	1		1	1	1	1					
Ranunculus sceleratus	1		1	1	1	1	1				
Persicaria hydropiper	1		1	1	1	1	1	1			
Typha latifolia	1			1	1	1	1	1			
Veronica anagallis-aquatica					1	1	1	1			
Polygonum aviculare					1	1	1	1			
Persicaria maculosa					1	1	1	1			
Chenopodium album					1	1	1	1			
Atriplex patula					1	1	1	1			
Sonchus asper					1	1	1	1	1		
Stellaria media					1	1	1	1	1	1	
Solanum nigrum					1	1	1	1	1	1	
Hordeum vulgare						1	1	1	1	1	
Rumex obtusifolius						1	1	1	1	1	
Galium species							1	1	1	1	1
Malus sylvestris							1	1	1	1	1
Erica tetralix							1	1	1	1	1
Urtica dioica							1	1	1	1	1
Galeopsis tetrahit								1	1	1	1
Conium maculatum									1	1	1
Humulus lupulus									1	1	1
Corylus avellana									1	1	1
Crataegus monogyna									1	1	1
Solanum dulcamara										1	1
Cladium mariscus		1	1	1						1	1
Rubus fruticosus ag.										1	1

Appendix 2D Overlapping taxon groups of sample C

1

29Aa3a 60.3	29Aa2b 65.5

2

16Ab4a 118.1	08Aa2 118.2	06Ac1 124.2	29Aa4 124.4	29Aa2b 124.4	08Bc2b 126.6
29Aa1 129.0	36Aa2a 129.3	16Ab5 130.1	09Aa1 131.9	16Bc1b 132.8	12Ba2b 133.7
06Ac3 133.8	06Ac4 135.2	09Ba1 135.9	28Aa2b 136.0	16RG2 137.2	09Aa3b 137.3
32Ba2b 137.5					

3

08Aa2 104.9	29Aa2b 109.1	29Aa4 112.9	12Ba2b 117.9	29Aa1 119.0

4

08Aa2 95.8	29Aa2b 109.4	29Aa4 110.2

5

29Aa3c 76.3	29Aa2b 84.7	29Aa3b 88.2

6

29Aa3c 123.7	29Aa3b 134.1	29Aa2b 137.8

7

31RG1 144.2	29Aa3c 150.6	29Aa3b 157.0	31Ab3c 157.7	31RG4 162.4

8

43RG3 126.7	43Aa5 138.8	43Aa4 144.9

9

43RG3 122.8	43Aa5 133.2	43Aa4 139.8

Appendix 2E Suggested syntaxa for sample A showing reduction by threshold in difference of index with most likely suggestion and exclusion of basal (RG) communities (crossed out). The numbers 1-9 in the top rows represent taxon groups. All syntaxon codes are followed by their weirdness value to be compared with the threshold calculated in Table 2.4

Box 1|061

A pure sample

Schepers, M.

ABSTRACT | Historic arable weed vegetation is generally regarded to be one of the ecotopes most likely to harbour a vegetation composition that can no longer be found today. To show the problems that can be caused by non-analogue vegetation during the analysis and interpretation of archaeobotanical data, both a phytosociological approach and an approach that divides the identified taxa into ecological groups were applied to a sample known to be derived from a pure sample of pressed buckwheat *(Fagopyrum esculentum)* fruits. As was expected, both methods divided the data into a number of groups, and both correctly pointed to arable weed vegetation as a major component. It is concluded that a combination of both methods, supplemented with archaeological data and some common sense, does allow for a more detailed, and thus improved, reconstruction.

KEYWORDS | Non-analogue vegetation · PALAEOASSOCIA · Phyto-sociology · Ecological groups · Arable weed vegetation

INTRODUCTION | In archaeobotanical studies, past arable weed vegetation is probably the most intensively studied vegetation type. Interest in this vegetation is triggered both by the fact that these communities are believed to possibly contribute to the understanding of past cultivation practices and by the fact that plant remains from possible arable weed taxa are well represented, if not overrepresented, in archaeological contexts.

It is generally accepted that the vegetation of past agricultural fields, in particular, is likely to differ from any present-day plant community. Less anthropogenically influenced types of vegetation are believed to be more comparable, especially from the second half of the Holocene onwards, when climatic conditions must also have been more or less comparable to the present conditions (Oldfield 2005). The non-analogue character of past arable weed communities is therefore not so much a consequence of different climatic conditions as of changes in agricultural practices. The complicated vegetation composition of arable weed communities is acknowledged in archaeobotany as well as in 'modern' vegetation science (e.g. Den Hartog 2001; Hillman 1991; Knörzer 1971; Sissingh 1950; Weeda *et al*. 2003a).

There are several approaches to the identification of (possible) past arable weed vegetation composition. In wetland sites, cereal remains are often found in charred condition. It is assumed that the remains of wild plant species with the same mode of preservation can be interpreted as having been subjected to the same processing activities and, by extension, probably originating from the same field (e.g. Pals 1999, 139; Out 2009a, 381–389). This assumption will allow for the identification of past arable weed vegetation even when the remains are mixed with waterlogged remains in the archaeobotanical record.

Not all arable weeds, however, are equally likely to be carried into the settlement along with the crop. Whether the arable weeds are included depends, in part, on the harvesting methods. Moreover, subsequent processing stages, such as sieving, will influence which arable weeds become charred along with the cereals (e.g. Cappers 2006; Kreuz and Schäfer 2011; Wilson 1984). For example, if sieving of the required amount of

Box 1|**063**

grain took place directly prior to further processing, the sieved-out smaller seeds may be put aside as waste and thus will not become charred as part of further (food) processing. When the bigger weed seeds (i.e. those not removed by sieving) become charred together with the cereal grains, these may be added to the unburned waste product and just put aside. The total waste product of the full cultural process may then be composed of both waterlogged seeds, primarily made up out of the smaller seeds that were sieved out, and some accidentally charred cereal grains and 'bigger' weed seeds that got charred with them. I recently suggested the possibility of such a scenario for the terp site of Achlum (Schepers in prep.).

Although the harvesting and processing stages may cause taxa to be absent from the archaeobotanical record that will have been present on the field in the past, finds of pure (processed) harvests provide the possibility to identify incomplete, non-analogue plant communities. Such examples of so-called *reine Proben* (pure samples) are highly valued in archaeobotany (Körber-Grohne 1967).

In this box, I take a closer look at an example of such a pure sample. It concerns a substantial amount of waterlogged pressed buckwheat *(Fagopyrum esculentum)* fruits recovered in the historic city centre of Coevorden (province of Drenthe, The Netherlands [see Fig. 1.6 for the location of Coevorden]). The area is known for the cultivation of buckwheat in dehydrated and subsequently burned peat bogs, a practice known as the so-called peat-burning culture. For an (agri)cultural overview, see Bieleman (1987, 560–570). For the original report on the excavation, including the exact location of the sample, see Lenting and Van Malssen (2011) and the botanical chapter therein (Out and Schepers 2011). Concentrations of buckwheat fruits have been encountered in various locations in the Netherlands, though mostly in latrines or cess pits (e.g. Kooistra *et al.* 1998; Schepers 2011; Van Haaster 2003, 2007). These reports all include arable weed seeds as well, but the presence of other crops besides buckwheat mostly obscures a direct association of crop and weeds.

The aim of this box is not so much to present a reconstruction of arable weed vegetation associated with the cultivation of

buckwheat as it is to experiment in the application of two different types of analysis to what is known to be a pure sample. Following the application, I briefly evaluate to what extent these two types of analysis confirm, contradict, or supplement each other.

METHODS | Several litres of the buckwheat deposit were recovered. Because it was recognized instantly as a buckwheat concentration, a small lump of it was kept aside to be stored and preserved in bulk (Fig. B1.1). The extreme compactness of the sample shows that we are, indeed, dealing with a pure sample. About 2 litres of it was carefully crumbled and sieved over sieves with aperture sizes of 2, 1, 0.5, and 0.2 mm.

The residues were studied intensively, and all non-buckwheat remains were picked out, identified, and quantified. The buckwheat remains were not quantified, but the sample most definitely represent tens of thousands of buckwheat fruits. The resulting taxon list was analyzed as a 'normal' archaeobotanical sample, ignoring for the moment that it is believed to represent a pure sample.

Two different approaches were used for the ecological interpretation of the sample. First, following an approach commonly used in archaeobotany in The Netherlands, all identified taxa were assigned to one of the main ecological groups defined by Arnolds and Van der Maarel (1979). Given the relatively small number of taxa identified, their further subdivision into more detailed groupings, while relevant in ecology, would have resulted in a large number of very small groups. The system by Arnolds and Van der Maarel (1979) assigns plant species to a single ecological group. This may be problematic with respect to species with broad ecological amplitudes (Tamis *et al.* 2004, 111).

Second, the recently developed PALAEOASSOCIA method was applied to the sample (Schepers *et al.* 2013b). Based on present-day phytosociology, this method relies quite heavily on the uniformitarian assumption. Its application to remains originating from an almost certainly non-analogue vegetation type serves primarily to evaluate how dramatic this expected discrepancy actually is.

Box 1**065**

RESULTS I As was to be expected given the nature of the sample, little volume was lost through sieving. Whereas the sieving of normal archaeobotanical samples serves mostly to eliminate the sediment component (e.g. sand or clay), in this case it served primarily to loosen the remains and catch most *Fagopyrum esculentum* fruits on the 'bigger' sieves. The density of non–*Fagopyrum esculentum* remains was extremely low. The remains that were found bore the unmistakable scars of having been incorporated in the pressing process and were often heavily fragmented. This is a common feature for arable weed remains from archaeobotanical contexts.

A total of 26 taxa were identified, most of them in low numbers (Table B1.1). No crop remains besides those of *F. esculentum* were present. With respect to the relatively high number of *Erica tetralix* leaves, we need to take into consideration that these concern single leaves; in other words, the high number may be misleading.

Results of the analysis following method 1, ecological grouping I Ecological grouping via the system published by Arnolds and Van der Maarel (1971) assigns the identified remains to five of their main groups.

Figure B1.1 Close-up of the buckwheat *(Fagopyrum esculentum)* compact sample. Note how the package consists of numerous loose valves of the original three-sided buckwheat fruits.

Group 1 and group 2 are closely related, the difference between them being primarily related to the degree of humidity. *Sphagnum* has been assigned to the category of heathland and mires (7) by me for this dataset. *Rumex acetosella* is the sole representative of dry grasslands and walls (6), whereas *Sambucus nigra* and *Urtica dioica* represent the group of deforestations, borders, and thickets (8). Both *Rumex acetosella* and *Urtica dioica* are generalist species, that are known to occur as arable weeds as well. In a 'real' report, these would probably have been assigned to a bigger group, whereby *R. acetosella* could just as well have been assigned to group 1 as to group 7.

Taxa	Plant part	n	Ecological group	Category
Fagopyrum esculentum	fruit	>10000	Crops	
Atriplex patula	fruit	1	Agricultural fields and rough growths	1
Atriplex prostrata	fruit	1	Agricultural fields and rough growths	1
Centaurea cyanus	fruit	9	Agricultural fields and rough growths	1
Chenopodium album	fruit	1	Agricultural fields and rough growths	1
Persicaria lapathifolia	fruit	6	Agricultural fields and rough growths	1
Persicaria maculosa	fruit	1	Agricultural fields and rough growths	1
Polygonum aviculare	fruit	2	Agricultural fields and rough growths	1
Scleranthus annuus	fruit	5	Agricultural fields and rough growths	1
Solanum nigrum	seed	1	Agricultural fields and rough growths	1
Sonchus asper	fruit	1	Agricultural fields and rough growths	1
Spergula arvensis	seed	9	Agricultural fields and rough growths	1
Stellaria media	seed	10	Agricultural fields and rough growths	1
Urtica urens	fruit	1	Agricultural fields and rough growths	1
Bidens tripartita	fruit	1	Disturbed soils on open, humid to wet, humus poor soils	2
Leontodon autumnalis	fruit	1	Disturbed soils on open, humid to wet, humus poor soils	2
Persicaria hydropiper	fruit	2	Disturbed soils on open, humid to wet, humus poor soils	2
Ranunculus repens	fruit	2	Disturbed soils on open, humid to wet, humus poor soils	2
Ranunculus sceleratus	fruit	8	Disturbed soils on open, humid to wet, humus poor soils	2

Box 1|**067**

Rumex acetosella	fruit	1	Dry grasslands and walls	6
Calluna vulgaris	leaf/branch	x	Heathland and mires	7
Erica tetralix	leaf	>150	Heathland and mires	7
Ranunculus flammula	fruit	3	Heathland and mires	7
Rhynchospora alba	fruit	1	Heathland and mires	7
Sphagnum	leaf	x	Heathland and mires	7
Sambucus nigra	fruit	1	Deforestations, borders and thickets	8
Urtica dioica	fruit	4	Deforestations, borders and thickets	8

Table B1.1 Results of the analysis of the *Fagopyrum esculentum* compact sample. The ecological groups and category numbers refer to Arnolds and Van der Maarel (1979)

Results of the analysis following method 2, PALAEOASSOCIA | The ordering of the PALAEOASSOCIA association matrix for the sample resulted in a total of nine groups (Table B1.2). Simply by observing the association matrix, these groups can be divided into two clusters. In the upper left corner of the matrix, groups 1–3 form an overlapping section of relatively few taxa. The second cluster is formed by groups 4–8, which all include a clear set of taxa with high association values (the green block). A third subgroup is formed by group 9. Not shown in the association matrix, it is compiled of the greatest possible group of mutually non-exclusive species, including *Sambucus nigra*. The groups have been analyzed using their species composition to find the best match with a present syntaxon, that is, a well-defined plant community. The results, summarized in Table B1.3, further confirm the three clusters as identified above. It proved difficult to convincingly assign the three taxon groups from the upper left cluster (1–3) to a defined plant community. On the class level alone, four different syntaxa are suggested. The moist pioneer communities of the *Bidentetea tripartitae* (class 29) are best represented. Plant communities within this class can develop spontaneously, but also, for example, in originally nutrient-poor environments as a consequence of anthropogenically caused eutrophication (Weeda *et al.* 1998). For cluster 2 (taxon groups 4–8) a much more consistent picture emerges. All suggested syntaxa fall within the *Stellarietea mediae*, the class of arable weed communities. The *Digitario-Setarion* (30Bb) alliance is most strongly supported through the analysis.

	TAXON	1		2	3	4	5	6	7	8			
7	CALUVUL0	***	-0,1	0,2	0,0	-0,2	-0,4	-0,4	0,0	-0,3	-0,6	-0,6	-0,3
7	RANUFLA0	-0,1	***	0,3	0,4	0,7	-0,3	0,2	0,1	0,1	-0,9	-1,8	-0,8
7	SPHG-SP0	0,2	0,3	***	0,4	0,1	-0,2	0,1	0,3	0,1	-0,3	-0,8	-0,3
7	RHYNALB0	0,0	0,4	0,4	***	0,5	-0,2	0,2	0,3	0,1	-0,2	-0,7	-0,3
1	POLNLAP0	-0,2	0,7	0,1	0,5	***	0,3	0,2	0,4	0,2	0,4	0,4	0,6
2	RANUSCE0	-0,4	-0,3	-0,2	-0,2	0,3	***	0,3	0,6	0,8	0,8	0,6	0,8
2	RANUREP0	-0,4	0,2	0,1	0,2	0,2	0,3	***	0,1	0,4	0,3	0,2	0,2
2	BIDETRI0	0,0	0,1	0,3	0,3	0,4	0,6	0,1	***	0,7	0,1	-0,2	0,5
2	POLNHYD0	-0,3	0,1	0,1	0,1	0,2	0,8	0,4	0,7	***	0,4	0,5	0,6
1	POLNAVI0	-0,6	-0,9	-0,3	-0,2	0,4	0,8	0,3	0,1	0,4	***	1,7	1,3
1	CENTCYA0	-0,6	-1,8	-0,8	-0,7	0,4	0,6	0,2	-0,2	0,5	1,7	***	1,3
1	POLNPER0	-0,3	-0,8	-0,3	-0,3	0,6	0,8	0,2	0,5	0,6	1,3	1,3	***
1	CHENALB0	-0,4	-1,0	-0,6	-0,5	0,6	0,6	0,1	0,1	0,4	1,5	1,9	1,5
1	SOLANIG0	-0,1	-0,5	-0,3	-0,3	0,4	0,6	0,2	0,0	0,3	1,2	1,3	1,4
1	SPERARV0	-0,3	-0,8	-0,3	-0,4	0,3	0,1	0,1	-0,1	0,4	1,4	1,9	1,4
1	SONCASP0	-0,2	-0,4	-0,4	-0,3	0,4	0,8	0,3	0,2	0,4	1,1	1,1	1,1
1	STELMED0	-0,3	-0,8	-0,4	-0,4	0,2	0,6	0,3	-0,1	0,4	1,2	1,4	1,1
1	URTIURE0	0,0	0,0	-0,2	-0,3	0,3	-0,2	0,1	-0,2	-0,2	1,0	1,3	0,8
1	ATRPPAT0	-0,1	-0,8	-0,6	-0,5	0,6	1,0	0,2	0,0	0,5	1,5	1,6	1,2
1	SCLEANN0	-0,4	-0,3	-0,4	-0,3	0,2	0,1	0,2	-0,1	0,2	1,1	1,6	0,8
8	URTIDIO0	-0,3	-0,7	-0,3	-0,4	-0,3	-0,2	0,2	0,1	0,0	-0,1	-0,2	0,0
	FAGOESC0	0,2	-1,1	-0,5	-0,7	-0,4	-0,1	0,0	-0,1	-0,1	0,1	0,3	0,2
6	RUMEACT0	0,3	0,5	-0,1	-0,1	0,3	-0,3	-0,1	0,0	0,1	0,4	0,8	0,4
1	ATRPPRO0	0,1	-0,1	-0,1	0,2	0,5	0,4	-0,3	0,4	-0,1	0,6	0,4	0,3
7	ERICTET0	0,8	-0,6	0,3	0,5	0,0	-0,2	-0,3	0,3	0,3	-0,1	0,0	0,0
2	LEONAUT0	-0,3	0,4	0,1	0,4	0,4	-0,3	0,6	-0,1	-0,2	0,2	-0,7	-0,2
8	SAMBNIG0	0,5	-0,9	-0,3	-0,7	-0,8	-0,6	-0,3	-0,3	-0,1	-0,9	-0,7	-0,4

Table B1.2 The association matrix for the sample. The numbers in the first column serve for comparison with the 'category column' in table B1.1. The top row indicates the start of each group (thick black frame). The blue frames indicate satellite taxa for group 1 and group 8. Group 9, including *Sambucus nigra,* is formed separately and not shown here

Its associations occur on acidic base-poor soils (Haveman *et al.* 1998). Group 9, including *Sambucus nigra,* is the only group for which a woodland community is suggested. According to the description of this association, it was present in burnt areas in the 19th century, as well as in the proximity of crop fields. The suggested subasso-ciation is even associated with dehydrated peat soils (Swertz *et al.* 1999, 85-87).

-0,4	-0,1	-0,3	-0,2	-0,3	0,0	-0,1	-0,4	-0,3	0,2	0,3	0,1	0,8	-0,3	0,5
-1,0	-0,5	-0,8	-0,4	-0,8	0,0	-0,8	-0,3	-0,7	-1,1	0,5	-0,1	-0,6	0,4	-0,9
-0,6	-0,3	-0,3	-0,4	-0,4	-0,2	-0,6	-0,4	-0,3	-0,5	-0,1	-0,1	0,3	0,1	-0,3
-0,5	-0,3	-0,4	-0,3	-0,4	-0,3	-0,5	-0,3	-0,4	-0,7	-0,1	0,2	0,5	0,4	-0,7
0,6	0,4	0,3	0,4	0,2	0,3	0,6	0,2	-0,3	-0,4	0,3	0,5	0,0	0,4	-0,8
0,6	0,6	0,1	0,8	0,6	-0,2	1,0	0,1	-0,2	-0,1	-0,3	0,4	-0,2	-0,3	-0,6
0,1	0,2	0,1	0,3	0,3	0,1	0,2	0,2	0,2	0,0	-0,1	-0,3	-0,3	0,6	-0,3
0,1	0,0	-0,1	0,2	-0,1	-0,2	0,0	-0,1	0,1	-0,1	0,0	0,4	0,3	-0,1	-0,3
0,4	0,3	0,4	0,4	0,4	-0,2	0,5	0,2	0,0	-0,1	0,1	-0,1	0,3	-0,2	-0,1
1,5	1,2	1,4	1,1	1,2	1,0	1,5	1,1	-0,1	0,1	0,4	0,6	-0,1	0,2	-0,9
1,9	1,3	1,9	1,1	1,4	1,3	1,6	1,8	-0,2	0,3	0,8	0,4	0,0	-0,7	-0,7
1,5	1,4	1,4	1,1	1,1	0,8	1,2	0,8	0,0	0,2	0,4	0,3	0,0	-0,2	-0,4
***	1,5	1,5	1,3	1,3	1,2	1,5	1,2	0,2	0,3	0,4	0,4	0,1	-0,1	-0,3
1,5	***	1,2	1,2	1,1	1,3	1,2	0,8	0,2	0,2	0,3	0,5	0,1	-0,2	0,0
1,5	1,2	***	0,8	1,2	0,5	1,0	1,3	0,1	0,3	0,9	-0,1	0,1	-0,2	-0,2
1,3	1,2	0,8	***	0,9	0,8	1,2	0,5	0,3	0,3	-0,1	0,5	0,0	0,2	-0,2
1,3	1,1	1,2	0,9	***	0,8	1,1	0,9	0,4	0,3	0,4	0,1	0,1	-0,1	0,2
1,2	1,3	0,5	0,8	0,8	***	1,0	0,8	0,3	0,2	0,4	0,3	0,0	0,0	0,0
1,5	1,2	1,0	1,2	1,1	1,0	***	0,9	0,2	0,3	0,1	0,7	0,0	0,0	-0,2
1,2	0,8	1,3	0,5	0,9	0,8	0,9	***	0,1	0,3	0,5	0,0	0,0	0,1	-0,1
0,2	0,2	0,1	0,3	0,4	0,3	0,2	0,1	***	0,4	-0,2	-0,1	0,0	-0,2	0,8
0,3	0,2	0,3	0,3	0,3	0,2	0,3	0,3	0,4	***	0,1	0,0	0,1	-0,1	0,5
0,4	0,3	0,9	-0,1	0,4	0,4	0,1	0,5	-0,2	0,1	***	0,0	0,0	0,0	0,0
0,4	0,5	-0,1	0,5	0,1	0,3	0,7	0,0	-0,1	0,0	0,0	***	0,1	0,2	-0,7
0,1	0,1	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,1	0,0	0,1	***	-0,2	0,5
-0,1	-0,2	-0,2	0,2	-0,1	0,0	0,0	0,1	-0,2	-0,1	0,0	0,2	-0,2	***	-0,4
-0,3	0,0	-0,2	-0,2	0,2	0,0	-0,2	-0,1	0,8	0,5	0,0	-0,7	0,5	-0,4	***

The numbers of the ecological groups from table B1.1 are presented in the first column of table B1.2 to allow for an easy comparison between both methods. Evidently, the species labelled as arable weeds (1) in the ecological groups overlap almost completely with the groups that have been identified as arable weed communities through PALAEOASSOCIA. The taxa assigned to ecological group 2 seem to match up quite well with the *Bidentetea tripartitae* communities from groups 2 and 3 in particular from the PALAEOASSOCIA analysis. The phytosociological analysis, however, did not result in the identification of a typical 'heathland and mire' association for

the groups in the upper left corner, whereas group 1, in particular, includes a number of species from this ecological group (7).

Code	1	2	3	4	5	6	7	8	9	Syntaxon name
30Bb1b				2	1	1	1	1	3	Spergulo arvensis-Chrysanthemetum euphorbietosum
30Bb2a				3	3	2	2	2		Echinochloo-Setarietum typicum
30Ab3				1	2		3	3		Chenopodio-Oxalidetum fontanae
29Aa1	2	1	1							Polygono-Bidentetum
31ca03a	4								2	Tanaceto-Artemisietum agrostietosum
28Aa4b	1									Digitario-Illecebretum digitarietosum
34Aa1b									1	Senecio-Epilobietum ceratocapnetosum
12Ba2			2							Triglochino-Agrostietum cardaminetosum
28Aa1b	3									Cicendietum filiformis juncetosum
29Aa3c			3							Chenopodietum rubri rorippetosum
29Aa2b			4							Rumicetum maritimi chenopodietosum

Table B1.3 Suggested syntaxa for the groups formed through the association matrix (table B1.2). The numbers indicate the order of the suggestion (1=first suggestion, 2=second suggestion, etc.). The syntaxa are arranged according to the number of times they have been suggested and, within that, according to their average suggested position. The colour scheme follows the field guide of Dutch plant communities (Schaminée *et al.* 2010). Light green: grasslands and heathland. Orange: coastal and inland pioneer communities. Dark green: rough, thicket, and woodlands

CONCLUSIONS I Both the ecological groups analysis and the PALAEOASSOCIA analysis proved insufficient for a full understanding of the *Fagopyrum esculentum* sample. Both methods allowed for the identification of arable weed vegetation, but at first sight they appeared to 'disagree' on the interpretation of the other taxa.

Although both types of analysis appear to contradict the interpretation of the sample as a pure sample, the nature of the sample leaves no room for doubt regarding its 'pure' nature. This means that plant species will be missing from the sample that would have been present in the past (incompleteness), but no species will have become mixed into the sample that did not occur in or directly next to the buckwheat field. A combination of the PALAEOASSOCIA analysis and the ecological groups allows for an interpretation that fits with the peat-burning culture known historically from the area. The arable weed communities as they have been recognized through PALAEOASSOCIA do not tell us that peat burning was being practiced. Ecological grouping, however, does directly hint at the presence of heathland and mires. The possible occurrence of *Bidentetea tripartitae* communities in this

Box 1|**071**

type of environment as a consequence of eutrophication, as well as the identification of a woodland community associated with burnt soil, adds up to a rather complete reconstruction.

The *Fagopyrum esculentum* concentration must indeed originate from a former bog environment, where rapid eutrophication was stimulated by dehydration and subsequent burning of the peat. The plot that was thus created was used for the cultivation of buckwheat. Typical arable weeds, such as *Scleranthus annuus* and *Centaurea cyanus,* were present among the crop, probably alongside *Rumex acetosella*. Near the wetter edges of the plot, species such as *Ranunculus flammula* and *Solanum nigrum* occurred, and along the ditches *Bidens tripartita* and *Persicaria hydropiper* occurred. Incidental specimens from species that originate from the pre-cultivation environment, such as *Calluna vulgaris* and *Erica tetralix,* must have been found occasionally in the field, but would have been found in greater numbers near the field. It cannot fully be excluded, however, that the remains of these plants represent specimens already 'dead' at the time that were possibly harvested through uprooting. However, the low numbers of *Sphagnum* leaves contradict this interpretation.

The reconstruction as thus presented shows that at least some of the association identifications made through PALAEOASSO-CIA must be wrong, or at least incomplete. This concerns, in particular, the plant communities identified for the subgroups in cluster 1 and is caused by the fact that these groups are relatively small. The arable weed communities were correctly identified as such, but the ecology of the identified associations is not in accordance with the peat-burning culture. This is readily explained by the fact that this type of agriculture was no longer being practiced when people first started describing arable weed vegetation systematically.

Many more pure samples, as well as more mixed (but still interesting) samples that may contain arable weed species and crops, are readily available through the Dutch archaeobotanical database RADAR (Van Haaster and Brinkkemper 1995). Analysis of these samples would not necessarily involve new 'primary' research. However, by combining different approaches, as presented here, our understanding of past arable weed vegetation and, subsequently, past plant husbandry will substantially increase.

Wet, wealthy worlds: The environment of the Swifterbant river system during the Neolithic occupation (4300–4000 cal BC)

Schepers, M.

ABSTRACT | This study presents an updated reconstruction of the vegetation that existed during the Neolithic habitation (4300–4000 cal BC) of the core area of the Swifterbant culture, namely, the small, eponymous river system in the northeastern part of the Flevopolder (province of Flevoland, the Netherlands). Because it is buried by younger sediments, this river system is exceptionally well preserved, both chemically and physically. Four main landscape elements are distinguished, namely, stream channels, river banks, floodplains and sand dunes. The vegetation during the Neolithic period is analyzed by dividing plant macro-remains species lists from three of the Swifterbant sites into groupings of species that are likely to have occurred together. The ecology of the most similar present-day plant communities is then used to infer a landscape position for all vegetation units.

Additional data derive from partly unpublished data relating to diatoms, palynology and geology. This leads to an impression of what the vegetation may have looked like, which is then used to interpret the exploitation possibilities for the human inhabitants. It is argued that the marine influence on the vegetation was minimal, that peat formation continued during habitation, that the exploitation of the river banks must have been seasonal and that local cultivation of cereals is likely.

KEYWORDS | Vegetation reconstruction · Swifterbant Culture · Seasonality · Plant macro-remains · Landscape exploitation ·

INTRODUCTION | The Swifterbant culture constitutes the earliest Neolithic of the Pleistocene sands and wetlands between the rivers Scheldt and Elbe' and covers the time span between ca. 5000 and 3400 BC (Raemaekers 1999, 11). Whereas the oldest phase (prior to 4600 BC) is fully Mesolithic, domesticated plants and animals are present in the later phases. However, wild plants and animals continue to play a major role in subsistence. The people of these Neolithic phases of the Swifterbant culture are therefore described as hunter-gatherer-farmers. Several cultural overviews have been published over the past fifteen years (Louwe Kooijmans 2005; Peeters *et al.* 2004; Raemaekers 1999, 2005). This paper focuses on the Neolithic phase (4300–4000 cal BC) of the Swifterbant culture in its core area: the small, eponymous river system in the northeastern part of the Flevopolder, the Netherlands (Fig. 3.1), hereafter referred to as the (river) system.[1] Following a series of excavations and publications in the 1970s and 1980s, the Nieuwe Swifterbant Project (new Swifterbant project) set out to deal with a number of remaining questions (Raemaekers *et al.* 2005). An as yet insufficient understanding of past vegetation composition and distribution in the Swifterbant river system seriously hampered several aspects of archaeological interpretation. The goal of this paper is to resolve this issue by applying a new method to both old and new samples of plant macro-remains (Schepers *et al.* 2013b). Samples from three sites, recovered during excavation, form the basis of this reconstruction (see Fig. 3.1 for their location). Swifterbant S3 and S4 are settlement sites located on the river bank, within 30 metres of each other (Raemaekers in prep.a; Van der Waals 1977). Swifterbant S25 lies approximately 4 kilometres upstream, on the edge of the river dune upon which sites S21–S24 are located. Swifterbant S25 itself, probably not a settlement site, is situated in clay sediments deposited on the edge of the dune (De Roever 1976; Geuverink *et al.* 2009; Raemaekers in prep.b).

The vegetation reconstruction thus achieved will be supplemented by data from other (eco-) archaeological proxies to address a number of issues, some of which have long been a matter of debate. This includes the degree of salinity in the system (e.g. Clason and Brinkhuizen 1978; Van Zeist and Palfenier-Vegter 1981),

whether habitation on the river banks was permanent or periodic (e.g. Raemaekers 1999, 41–42; Zeiler 1986), and whether cereal cultivation took place (e.g. Cappers and Raemaekers 2008; Out 2009a, 179; Van Zeist and Palfenier-Vegter 1981). Some remarks will also be made with respect to peat formation and the difficulties of detecting changes in the ecology during the period under study.

Geomorphology | The Swifterbant river system, which is currently covered by 1–2 metres of sediment, was discovered during systematic pedological and geological investigations after land reclamation in the Polder Oost Flevoland (Van der Waals and Waterbolk 1976, 4). The system is situated on the far, landward end of a coastal lagoon (Ente 1976, 18) that opens towards the west (the present-day North Sea), and it is fed from the east by the river IJssel (Ente 1976, 14; see also Vos and Kiden 2005 for a more recent general overview). By integrating data from extensive coring and present-day elevation maps, a detailed reconstruction map of the system was produced by Dresscher and Raemaekers (2010), partly based on the earlier work by Ente (1976).

Basically, four geomorphological units make up the landscape in the region: rivers, river banks, floodplain and sand dunes. Open water, that is, ponds, will have been present in the floodplain as well. The formation process of the river banks at Swifterbant is atypical. The formation of banks along stream channels is caused by the deposition of sediments when the water level in the channel rises and floods out of its normal bed. The flow velocity of water flooding out of the channel drops substantially, causing heavier particles in suspension to settle down. In most cases, these heavier particles will primarily consist of sand. In the case of the Swifterbant river banks, however, these heavier particles do not consist of sand, but of lutum particles bound together. This so-called flocculation typically occurs when fresh and saline water mix, a phenomenon that explains the river bank formation at Swifterbant (Schepers and Woltinge in prep.).

Research history of the study area | Because of the excellent preservation conditions, several studies have been carried out dealing (in part) with the landscape and the natural vegetation (Table 3.1).

The present study focuses on the vegetation in the Neolithic occupation phase of the Swifterbant river system. The study carried out by Van der Linden (2008) and the extensive and thorough palaeoecological chapters in the N23/N307 excavation report (Hamburg *et al.* 2013) provide extensive information on the ecology of the dunes during the Mesolithic occupation.

A reconstruction of available vegetation types in the vicinity of the Swifterbant S3 site is presented by Van Zeist and Palfenier-Vegter (1981). Their vegetation reconstruction is further refined by Out (2009a, 177–178).

Author	Plant macro-remains	Pollen	Wood
Casparie *et al.* 1977	S3	S3	S3
Van Zeist and Palfenier-Vegter 1981	S3		
De Rooij 2006*	S4		
Van der Veen 2008*		S4	
De Moor *et al.* 2009	HZL	HZL	
Prummel *et al.* 2009	S2		
Maurer 2011*	S25	S25	
Van der Laan 2011*			S25
Schepers *et al.* 2013b	S4		
Schepers and Bottema-Mac Gillavry in prep.	S4	S4	S4

Table 3.1 Overview of archaeobotanical research relating to the Swifterbant river system. Unpublished student reports are indicated by '*'. The prefix S stands for Swifterbant. HZL refers to Hanzelijn. For locations, see Figure 3.1

MATERIALS AND METHODS | Sampling and processing | Different sampling strategies were used at the three sites dealt with here. Two main sample categories are present at all three sites. Wet samples were secured in the field and sieved in the laboratory using a stack of sieves with mesh apertures ranging from 5 mm to 200 μm. 'Sieve residues' are the result of sieving on-site with a mesh aperture of 2 mm. Although many wild plant seeds will not be recovered on-site by this method, these residues do contain numerous remains of plants that may have been of economic

significance instead. Many economic plants have relatively large remains (e.g. *Corylus avellana* [hazel] and *Crataegus monogyna* [hawthorn]). Three drift line samples were taken near S4. These samples are not from the settlement proper. The volume of each of these samples is large, more than 10 litres (Schepers *et al.* 2013b). All of the samples were analyzed. Sieve residues from the S4 settlement layers were analyzed (Schepers and Bottema-Mac Gillavry in prep). At S3, 46 samples of 1 litre from settlement layers and all the sieve residues from the settlement layers were analyzed by Van Zeist and Palfenier-Vegter (1981). Finally, eight samples from the Swifterbant S25 river dune site were analyzed (Maurer 2011). The S25 site is located on the edge of the river dune. The samples mentioned here originate from clay and peat layers dating to the Neolithic period, so technically not from the dune itself. Sieve residues from the find layers at S25 (not necessarily settlement layers) were analyzed by Schepers and Palfenier-Vegter (Raemaekers in prep.b). For the complete species lists and a description of sampling methods for the individual sites, the reader is referred to the site reports (Maurer 2011; Schepers and Bottema in prep.; Van Zeist and Palfenier-Vegter 1981).

Some additional sampling was done in the buried back swamps near the present-day village of Swifterbant, based on a coring campaign near the Rivierduinweg by Nales (2010). At five locations, the top of the peat layers was sampled to determine the local vegetation at the time of peat formation (using Mauquoi and Van Geel 2007). These results will only be dealt with briefly, as this area is not representative of all Swifterbant back swamps and the peat layers cannot be directly correlated to the habitation period of S3, S4 and S25. The analysis only serves to increase our insight into the vegetation diversity of the back swamp area.Taxon names follow Van der Meijden (2005), syntaxon codes and names follow Schaminée *et al.* (1995a, 1995c, 1996, 1998) and Stortelder *et al.* (1999). All macro-remains are referred to as seeds and all microfossils as pollen, even when this is biologically incorrect. Furthermore, taxa are referred to as species unless a more precise taxonomic level is inevitable.
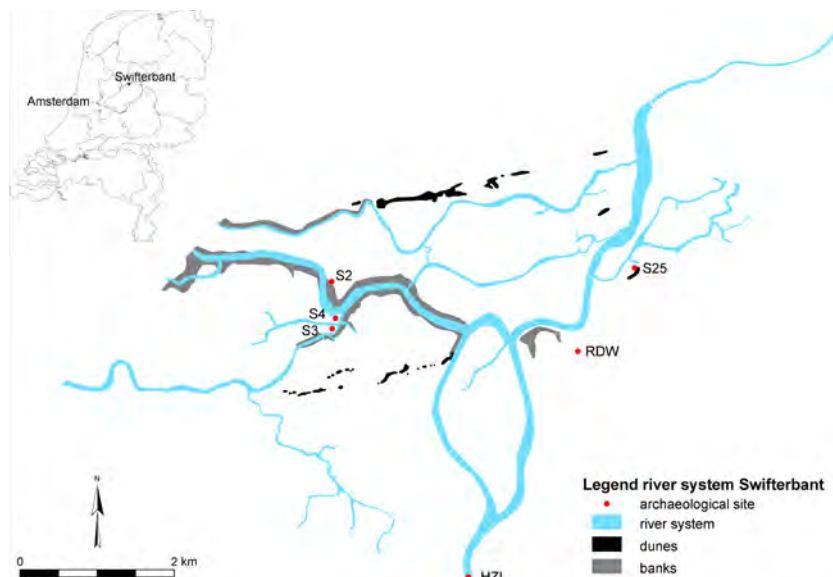
Figure 3.1 Map of the Swifterbant river system showing the location of the sites used for the interpretation of the vegetation. See Table 3.1 for sources. Samples from S3, S4 and S25 form the basis for the vegetation reconstruction. Data from S2 and HZL are used for a more complete interpretation in the discussion section. Some additional cores were taken at RDW (Rivierduinweg) for the present study, based on the report by Nales (2010). Map after Dresscher and Raemaekers (2010)

Palaeoassocia | The PALAEOASSOCIA package is a new method for identifying plant communities, already tested for the drift line samples from S4 (Schepers *et al*. 2013b). In this paper, the method is used to analyze samples from S3 and S25. The nature of the samples from S2, HZL and Rivierduinweg makes them unsuitable for this type of analysis. Because this paper targets both specialist and non-specialist audiences, some of the terminology involved in plant sociology, as well as PALAEOASSOCIA itself, requires a short introduction.

Plant communities are specific assemblages of plant species that occur under a certain combination of abiotic conditions, such as light, moisture and nutrient availability (for an introduction, see Braun-Blanquet 1964). A recognized combination of species, a plant community, is called a 'syntaxon' (plural syntaxa). Syntaxa, like taxa, are structured in a hierarchical system, each with its own suffix, ranked from class (-etea), via order (-alia) and alliance (-ion), to the most detailed level of the

association (-etum). Because of the rank of syntaxa is implied by their suffix, the rank will not be mentioned for the remainder of this paper. Furthermore, for the sake of brevity, syntaxon names will be referred to by their short name after first mention (e.g. *Bidention tripartitae* is thereafter referred to as *Bidention*). The most commonly used rank in field ecology, the 'species level' in plant communities, is the association. Just like a plant species, this rank of a community has the advantage that it can actually be witnessed as such.

The vast majority of archaeobotanical samples consist of a mixture of species from different plant communities. There are several ways to disentangle this mixture, of which a division in groups such as 'arable weeds', 'water plants' and 'trees and shrubs' is the most common one. PALAEOASSOCIA, however, calculates the probability that species in a sample may have grown at the same location, based on a comparison with a large data bank of present-day vegetation studies. If the sample is indeed a mixture, this will result in a number of overlapping groups. Therefore, where the term 'groups' is mentioned in this paper, this relates to a subset of a sample, consisting of species that can occur together in vegetation. These groups are compared with currently well-described plant communities. In many cases no single community provides a perfect match; in that case the package provides a number of suggested syntaxa (Fig. 3.2).

Archaeobotanical species lists frequently include unspecific identifications that could imply two or more species. All examples of this phenomenon contained in the present dataset commonly occur in Dutch archaeobotanical datasets – for example, *Chenopodium glaucum/rubrum* (e.g. De Moor *et al.* 2009; Gehasse 1995) and *Atriplex patula/prostrata* (e.g. Brinkkemper 1993; Buurman 1996). PALAEOASSOCIA does not accommodate groups of taxa as such. In the case of multi-taxa entries, all species involved are used in the analysis individually, for two reasons. First, species with narrow ecological amplitudes differing from the other species encountered in the sample will be easily identified in either the association matrix or the plant community identification stage. Second, species with broad ecological amplitudes may indeed have co-existed within the region.
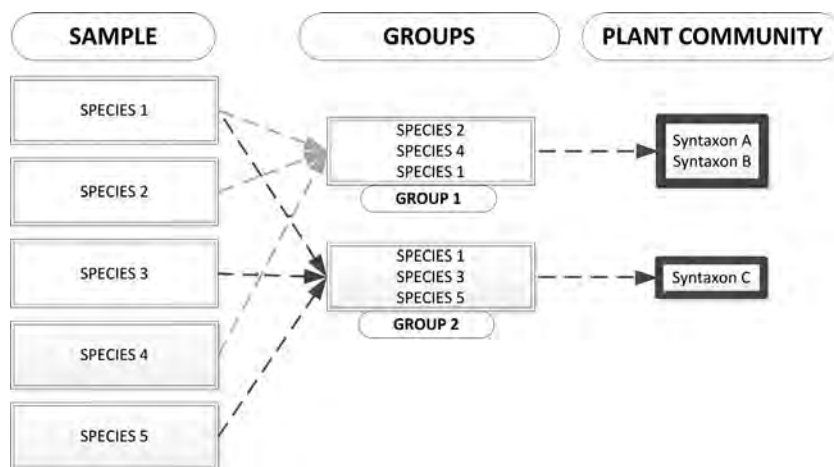
Figure 3.2 Simplified visualization of the palaeoassocia method, showing the three main steps. An archaeobotanical sample consisting of a mixture of species from several vegetation types (left) is divided into groups of species that can occur together (middle). The method then identifies that group as one or more possible most similar present-day plant communities (right)

The list of suggested syntaxa is reduced following the methodology presented in Schepers *et al.* (2013b), but some cautionary comments need to be made. This reduction is partly based on the likeliness of an individual identification being right or wrong. A number of genera (the plural of genus, being the taxonomic level above species) are, or can be, represented by several species for which the possibility of a misidentification cannot be ruled out. To assess the possibility of misidentification, the Dutch archaeobotanical database RADAR was used to evaluate which taxa are often grouped together in identification or are identified to the genus level only (Van Haaster and Brinkkemper 1995, version 2006). The genera for which this is considered a possibility are *Arctium*, *Bolboschoenus/Schoenoplectus*, *Carex* and *Persicaria*. All species resulting from a splitting up of unspecific identifications are also not taken into account at this stage (e.g. either of the two species resulting from the splitting up of *Atriplex patula/prostrata*), unless both species are present in a group and both are obscuring the syntaxon (see for detailed explanation Schepers *et al.* 2013b).

Species that are 100% weird to all suggested syntaxa are ignored, since they are apparently unrelated to the whole set, despite initially ending up in the same association matrix

group. Crab apple (*Malus sylvestris*) is rarely identified in modern relevés because it is virtually impossible to distinguish it with certainty from any of the modern apple cultivars (Van der Meijden 2005, 391). Furthermore, this species may have been tended or even planted because of its economic significance in prehistory. The only crop plant in the taxon list, barley (*Hordeum vulgare*), is also ignored here. The final exception is *Cladium mariscus*. In this case, the high weirdness values are not considered a valid reason to exclude a syntaxon, because an as-yet-unsolved bug in the software causes this species to have higher association values with a lot of taxa than can realistically be expected based on its ecological characteristics. However, this software glitch does not prevent us from identifying the *Cladietum marisci* altogether, because in this plant community, the eponymous *C. mariscus* will obviously not be an uncommon species.

The samples from S3 and S25 were analyzed with PALAEOASSOCIA to identify the most likely plant community or communities represented by these groups. The data thus produced were added to the results from the S4 drift line samples.

With respect to the syntaxa identified from the drift line samples, two minor alterations were made. First, syntaxon 30Bb1b (*Spergulo arvensis-Chrysanthemetum euphorbietosum*) is discarded because of the absence of *Fallopia convolvulus* in the samples. This species is present in over 95% of the present-day relevés of that type. Secondly, syntaxon 29Aa3c (*Chenopodietum rubri rorippetosum*) is allowed as a possible plant community because the species initially preventing it from ending up as a possible suggestion, *Bolboschoenus maritimus*, is no longer accepted here as a valid species for discarding a syntaxon.

All samples analyzed are categorized into four main categories of vegetation structure, following Schaminée *et al.* (1995a, 1995c, 1996, 1998) and Stortelder *et al.* (1999), namely, (1) open water and marshes; (2) grasslands and heathlands; (3) coastal and inland pioneer communities; and (4) rough, thickets and woodlands. For reasons of brevity, these will be referred to as (1) wet communities, (2) grassland communities, (3) pioneer communities and (4) woodland communities.

Syntaxa suggested more frequently are considered to reflect correct identifications with a higher reliability. Because the number of samples studied per site differs, a comparison based on absolute numbers is of little value. Instead, the syntaxa are categorized into five main categories, by percentage of the most frequently identified syntaxon per site and vegetation structure. These categories are 4 (100-75%), 3 (75-50%), 2 (50-25%) and 1 (25->0%). Syntaxa only suggested once are indicated by a '+'. For example, the most frequently identified syntaxon in the pioneer communities for the S3 site was suggested 50 times. All syntaxa suggested more than 38 times (>75%) are in category 4, syntaxa suggested between 25 and 38 times are in category 3, and so forth. Syntaxa only suggested once for all three sites are omitted from the list.

RESULTS PLANT COMMUNITIES | The 46 samples from S3 were split into a total of 266 groups. The eight samples from S25 resulted in a total of 32 groups, leading to a total of 298 groups to be analyzed using PALAEOASSOCIA. Eleven syntaxa were considered a misidentification because a species vital to that vegetation type was missing in the samples, while the species is normally easily recognized and frequently found in archaeobotanical research.[2] Thus the total number of plant communities identified is 43 (Table 3.2). Unless otherwise specified by means of a citation, information on syntaxa in this section is derived from Schaminée *et al.* (1995a, 1995c, 1996, 1998), Stortelder *et al.* (1999) and the vegetation expert system SynBioSys (Hennekens *et al.* 2010). The identified syntaxa are described here individually and including their intersyntaxonomic relationships. The codes between brackets serve for an easy comparison with Table 3.2.

Code	Syntaxon name	S3	S4	S25
08Aa2	Polygono-Veronicetum anagallidis-aquaticae (p)		4	+
08Ba2b	Cicuto-Caricetum menyanthetosum (p)	2		4
08Bb2	Scirpetum tabernaemontani (p)	1	+	
08Bb4a	Typho-Phragmitetum typhetosum angustifoliae (p)	3		
08Bb4c	Typho-Phragmitetum typicum (p)	3		4

Code	Name			
08Bc2b	Caricetum gracilis comaretosum (p)	+	2	
08Bd1	Cladietum marisci (p)		2	
09Aa3b	Carici curtae-Agrostietum caricetosum diandrae (p)	2		
09Ba1	Scorpidio-Caricetum diandrae (p)	4		
12Ba2b	Triglochino-Agrostietum nasturtietosum	4		+
12Ba2c	Triglochino-Agrostietum juncetosum gerardi	2		
27Aa2c	Centaurio-Saginetum epilobietosum	1		
29Aa1	Polygono-Bidentetum	+		4
29Aa2b	Rumicetum maritimi chenopodietosum	3	4	+
29Aa3a	Chenopodietum rubri spergularietosum	1	1	
29Aa3b	Chenopodietum rubri inops	3	1	+
29Aa3c	Chenopodietum rubri rorippetosum	4	2	+
29Aa4	Eleocharito acicularis-Limoselletum	+	2	
30Ab1a	Veronica-Lamietum typicum	1		
30Ab1b	Veronica-Lamietum alopecuretosum	3		
30Ab3	Chenopodio-Oxalidetum fontanae	2	+	
30Bb1a	Spergulo arvensis-Chrysanthemetum typicum	1		
31Aa2b	Erigeronto-Lactucetum erysimetosum	3	+	
31Ab1a	Urtica-Malvetum atriplicetosum	1		
31Ab2c	Hordeetum murini arctietosum	1	1	
31Ab3a	Balloto-Arctietum typicum	2	1	
31Ab3b	Balloto-Arctietum diplotaxietosum	1		
31Ab3c	Balloto-Arctietum verbascetosum	4	2	
31Ca1b	Echio-Melilotetum	1	1	
32Ba2a	Soncho-Epilobietum typicum	1		3
32Ba2b	Soncho-Epilobietum althaeetosum	1		
37Ab1a	Pruno-Crataegetum typicum	+	4	
37Ac4	~~Pruno spinosae-Ligustretum~~	1		
38Aa1b	Artemisio-Salicetum agrostietosum stoloniferae	4		
38Aa2a	Irido-Salicetum menthetosum	3		4
38Aa2b	Irido-Salicetum alopecuretosum pratensis	2		4
38Aa3a	Cardamino amarae-Salicetum anthiscetosum	1		
39Aa2b	Carici-elongatae-Alnetum cardaminetosum amarae (p)	2		
39Aa2c	Carici-elongatae-Alnetum ribetosum nigrae (p)	+		4

43Aa1a	Violo odoratae-Ulmetum allietosum		3	
43Aa1b	Violo odoratae-Ulmetum inops	1		
43Aa3b	Crataego-Betuletum menthetosum			3
43Aa4	Carici remotae-Fraxinetum		+	3
43Aa5	Pruno-Fraxinetum	+	4	3

Table 3.2 Suggested syntaxa by site for three of the Swifterbant sites. Syntaxa are arranged according to their syntaxon number. This facilitates an easy comparison with the results (section 3). The colour scheme follows the field guide of Dutch plant communities (Schaminée *et al.* 2010). Blue: wetlands. Light green: grasslands. Orange: pioneer. Dark green: woodlands. Within these categories, numbers indicate the frequency with which syntaxa have been identified, expressed as a percentage of the most frequently identified syntaxon for that site: 4 (75–100%), 3 (50–75%), 2 (25–50%) and 1 (>0–25%). Syntaxa only suggested once are indicated with a '+'. The crossed out syntaxon is discarded on ecological grounds. A '(p)' indicates that this plant community is part of a hydrosere related to peat formation

Wet communities | Wet communities are represented by the *Phragmitetea* (08), including reed swamp communities and tall sedges and two syntaxa from the *Parvocaricetea* (09, small sedges).

Within the *Phragmitetea,* one association in the *Nasturtio-Glycerietalia* (08A) is present. This comprises communities of shallow, moving water. This movement can be both vertical and horizontal and can therefore not be seen as synonymous to running. The *Polygono-Veronicetum anagadillis-aquaticae* (08Aa2) is closely related to communities within the *Bidentetea tripartitae* (29, see 'Pioneer communities') and is characteristic of tidal movement in fresh water environments. The association indicates moving water, which fits the fact that it has not been recognized in the settlement samples from S3, but is dominant in the drift line samples from S4.All other plant communities in this class are within the *Phragmitetalia* (08B), which consists of communities indicative of standing or slightly moving water. For the Swifterbant area, different associations within this order are identified. They comprise closely related plant communities, which will all have co-existed in the area at some moments in time, yet were spatially distributed according to their particular tolerances. The *Cicuto-Caricetum menyanthetosum* (08Ba2b) is a subassociation of the *Cicuto-Caricetum pseudocyperi*. Nowadays, this association thrives in dug-out peat pits, which were absent in prehistory. But it also occurs on floating islands and old terres-

trialized stream channels, landscape elements that must have been abundantly present in the Swifterbant area. Open water with slightly brackish conditions is indicated by the *Scirpetum tabernaemontani* (08Bb2), which is often found in association with the more fresh water, but also slightly brackish *Typho-Phragmitetum* (08Bb4). Within this association, the 'salt marsh' species *Aster tripolium* may have occurred as well (see 'Salinity'). The predominance of the *Typho-Phragmitetum* indicates that, although some brackish influence in the river branches occasionally occurred, fresh water conditions were dominant. The *Caricetum gracilis comaretosum* (08Bc2b) appears to occur where silt or organic material is deposited.

The two associations within the *Parvocaricetea* (09) are only identified in the S3 settlement samples, and share a great number of species. They point in the direction of terrestrialization of sandy soils in a peat fen. The fact that these are only indicated or documented for the settlement site S3 probably indicates that they represent a signal from the back swamp areas behind the levees proper, unaffected by the occasional brackish influence present in the Swifterbant river system.

Grassland communities | The only grassland association identified is the *Triglochino-Agrostietum stoloniferae* (12Ba2). All grassland types within its class are indicative of trampled places and can cope with very dynamic conditions. From the two sub-associations identified, the *Triglochino-Agrostietum juncetosum gerardi* (12Ba2c) gives a slight indication for brackish conditions. This is primarily caused by the presence of its eponymous species, *Juncus gerardii*. The other subassociation (*Triglochino-Agrostietum nasturtietosum*, 12Ba2b) is located along stream channels and pools in wet marshes previously in direct connection with the sea. The genus *Triglochin* in the syntaxon name refers to the fresh water species *T. palustris* and not the salt marsh species *T. maritima*. This subassociation shares a number of species with related associations within the *Bidentetea* (29, see 'Pioneer communities') and can appear after succession from associations within the *Caricion nigrae* (09Aa), the *Phragmition australis* (8Bb) and the *Sparganio-Glycerion* (08Aa), all present among the wet communities identified in this analysis.

Pioneer communities | Twenty pioneer plant communities are suggested. Since fourteen of these communities fall within three alliances, the description of the pioneer communities below will focus on these three alliances.

All associations within the *Bidention tripartitae* (29Aa) have been identified for the Swifterbant region. The *Bidention* is the only alliance represented strongly at all three sites. Its dominance is confirmed by the large number of diagnostic species present in the datasets, including *Bidens tripartita*, *Persicaria hydropiper* and *Ranunculus sceleratus*. The communities occur on nitrogen-rich soils that are inundated in winter and may fall dry in summer, but will hardly ever dry out. The plant communities occur naturally along waterways, but may benefit from anthropogenic influence in avoiding their place being taken over by vegetation types classified within the *Phragmition* (08Bb, see 'Wet communities'). The best represented community overall is the *Rumicetum maritimi chenopodietosum* (29Aa2b), which can gradually transfer into the very well-represented *Chenopodietum rubri* (29Aa3) under a moderate grazing regime and low ground water level. Whereas the analysis from the S3 and S4 sites shows great similarity (although the *Chenopodietum* is better represented at S3), the situation at S25 is different and deserves some extra attention. The best represented association at S25 is the *Polygono-Bidentetum* (29Aa1), which differs the most from other associations in this class because it can cope with slightly more shade.

Both the *Stellarietea mediae* (30) and the *Artemisietea vulgaris* (31) are classes of anthropogenic vegetation types, being the 'arable weed' communities and the 'ruderal places' communities, respectively. They are evidently better represented in the S3 settlement samples than in the S4 drift line samples, and are fully absent from the river dune site S25.

Plant communities within the *Artemisetea* (31) are indicative of an environment where constant light grazing and other disturbances, such as trampling, occurred. They also benefit from waste depositions and become less common with an increase in human hygiene. It should be mentioned here that a number of species characteristic of the identified syntaxa, such as *Ballota nigra,* are rarely found in archaeobotanical samples

predating the Roman era. The best supported alliance within the class, the *Arction* (31ab) occurs on ammonia-rich soil. The *Chenopodietum* (29Aa3) is a community often found nearby, as is the *Pruno-Crataegetum* (37Ab1, see 'Woodland communities') when disturbance ceases.

Woodland communities I Thirteen (sub)associations were identified in the woodland vegetation group, representing five alliances. Two associations were identified within the *Rhamno-Prunetea*. The *Pruno spinosae-Ligustretum* (37ac4) is indicative of rocky outcrops and is currently only found in the south of the Netherlands. Due to the absence of rocky sediments near Swifterbant, its presence in the region is very unlikely. The *Pruno-Crataegetum typicum* (37Ab1a)*, on the other hand, is found on annually inundated (sandy) clay in large river deltas or channels. Although the Swifterbant river system was not a 'large' river, the incidental occurrence of this plant community cannot be excluded.

Several communities within the *Salicion albae* (38Aa) are represented. The *Artemisio-Salicetum agrostietum stoloniferae* (38Aa1b) can occur as pioneer vegetation on newly-formed soils along rivers (e.g. point-bars, wash-over deposits and crevasses splays). Depending on sedimentological and hydrological conditions, it can be succeeded by associations within the alliance, such as the *Irido-Salicetum albae* (38aa2), also identified in the Swifterbant data. When the bank is eroded it can be succeeded by, among others, associations within the *Bidention* (29Aa, see 'Pioneer communities'). The alder carr is represented by two varieties of the *Carici elongatae-Alnetum* (39Aa2), one of the two associations within the class. This syntaxon differs from the other association, the *Thelypterido-Alnetum,* by its closer relation to the *Alno-Padion* (43Aa) communities and a relatively high presence of nitrophilous species, including *Galium aparine* and *Urtica dioica*. Within the *Alno-Padion*, we see a strong representation of the *Pruno-Fraxinetum* (43Aa5), which is characterized by the presence of nitrophilous species as well.

RESULTS SIEVE RESIDUES I The analysis of the sieve residues in particular contributes to the understanding of the prehistoric food

economy, because this provides a better insight into the economic plant composition. Table 3.3 shows the results of the study of sieve residues from S3, S4 and S25.

Taxon	Plant part	s3	s4	s25
Alnus glutinosa	cone	+	19	37
Corylus avellana	fruit	+	71	6
Crataegus monogyna	endocarp	+	12	34
Galium aparine	seed	+	36	1
Malus sylvestris	exocarp	+	1	1
Ceratophyllum	fruit	1	1	
Hordeum vulgare	fruit	++	86	
Triticum turgidum subsp. dicoccum	fruit	+	23	
Ficaria verna	tuber		28	1
Quercus	fruit / cupule		1	32
Nymphaea alba	seed	+		
Phragmites australis	fruit	+		
Hordeum vulgare	rachis		2	
Cenococcum geophilum	sclerotium			39
	n		119	101

Table 3.3 Number of sieve residue samples in which taxa occur at three of the Swifterbant sites. Bold numbers indicate the top three taxa per site; The prefix S stands for Swifterbant. The taxa are ordered according to the site where they occur, in the following order: all three sites; S3 and S4; S4 and S25; S3; S4; S25. ++ = common, + = present. Plant part is seed or fruit s.l. unless other terms are mentioned

The data published by Van Zeist and Palfenier-Vegters (1981, 118, table 3) cannot be presented in the same way as those from S3 and S4, since the authors present the total number of remains instead of the number of samples. The strong presence of *Ficaria verna* tubers at S4 suggests they were somehow not recognized at S3. The inverse probably applies for the stem fragments of *Phragmites australis,* which have not been identified at S4. *Galium aparine* is not mentioned in their table 3, but was found in their sieve residues according to the text (Van Zeist and Palfenier-Vegter 1981, 131). Species only found once at a single site have been omitted for this study.

The most striking difference between river bank sites S3 and S4, on the one hand, and river dune site S25, on the other, is the absence of cereal remains at S25. The few samples from river bank site S2 are in this respect comparable to those from S3 and S4 (Prummel *et al.* 2009, 24). Furthermore, *Corylus avellana* and *Quercus* (probably *robur*) show opposite patterns. Whereas hazel is very commonly present at S3 and S4 but rare at S25, oak is virtually absent at S3 and S4 and quite common at S25. The high values of *Cenococcum geophilum* at S25 point in the direction of somewhat drier conditions and may relate to the surfacing of the sandy subsoil at that location (Van Geel 1978, 16,102).

INTERPRETATION AND SPATIAL DISTRIBUTION | Stream channels and ponds | Although the vegetation in and along the banks of the different river branches will have differed over space and time (see discussion: Time depth), it will have been dominated by the *Phragmition australis* (08Bb). Along the main channel, club-rushes will have formed a major component of the first line of vegetation. The culms of several club-rushes, including *Schoenoplectus lacustris* (both subsp. *lacustris* and subsp. *tabernaemontani*) and *Bolboschoenus maritimus*, are more rigid than *Phragmites australis* (reed) and will therefore be better able to withstand moving water. The club-rushes will be less commonly present along the secondary and tertiary channels, but will appear in deeper parts of standing water, for example, in open areas in the back swamps. On more open parts of the bank, specific vegetation types for small river banks will have become established. This openness can be caused by erosion, sedimentation (creating new substrates) or human clearance of the banks. Plant communities dominated by tall sedges were present at places where ongoing sedimentation within reed vegetation reduced the relative water level (see section 5, 'Floodplain fens and peat formation'). There is some evidence of floating islands as well. They will not have been present in the main channel, but in open water in marsh ponds in the back swamps. Given the low availability of peaty, sandy substrate in the Swifterbant region, the coverage of the *Cladietum marisci* (8Bd1) was probably lower than that of the *Phragmition* communities. A number of plant communities are

present that suggest mesotrophic conditions (9Aa3b and 9Ba1, see Table 3.2), but the nutrient availability in the area suggests that their distribution must have been sparse (see discussion: Flood-plain fens and peat formation).

With respect to plant communities within the *Phragmition* (08Bb), it must be noted that these communities can be very poor in species, and in many instances consist almost entirely of the type-species. Therefore, it is invalid to exclude the presence of the *Scirpetum lacustris* (consisting primarily of *Schoenoplectus lacustris* subsp. *lacustris*) in the area, given the very modest and incidental brackish signal (see discussion: Salinity). Following the same line of reasoning, species-poor plant communities of deeper water will also have been present, but are undetectable for methodological reasons. For example, the presence of plant communities belonging to the *Potametea* is very likely, but now hidden within associations of the *Phragmitetalia* (08, Fig. 3.3). Relatively pure patches of (yellow) water lily (*Nymphaea alba* / *Nuphar lutea*) may well have been present in the deeper parts of cut-off stream channels and ponds.[3]

Figure 3.3 Zonation of species-poor plant communities of reed *(Phragmites australis = Typho-Phragmitetum,* left: bright green) and club rush *(Schoenoplectus lacustris* subsp. *lacustris = Scirpetum lacustris,* right: dark green). White water lilies *(Nymphaea alba)* float between the culms of both species (and hence occur in both communities), but they also occur in their 'own' community *(Myriophyllo-Nupharetum)* in the background (Buchholz, Germany, august 2012)

Exploitation of stream channels and ponds | The settlement layers of the Swifterbant river bank sites S4 and S3 may have been ar-

tificially raised with reed bundles (Van der Waals 1977, 18). In addition, last year's reed vegetation may have been burnt down to clear the shores, which would explain not only the high number of charred reed stem fragments, as recognized by Van Zeist and Palfenier-Vegter (1981), but also the high number of *Galium aparine* (cleavers) fruits encountered at the site. Although *G. aparine* is not typically for a *Phragmition*, field observations by the author show that reed vegetation bordering 'disturbed soils' provide an excellent climbing opportunity for this species (but for other explanations, see Out 2009a, 344–345). Recent Palaeolithic research in Belgium tried to interpret the burning of reed as reflecting attempts by prehistoric people to attract large herbivores (Bos *et al.* 2013), but in the Swifterbant wetland this explanation seems unlikely. The channels will also have been the areas where fish were caught. The analysis of fish remains indicates a strong presence of fish characteristic of the so-called bream zone (Brinkhuizen 1976; Hullegie 2009). In this zone, the current flow velocity was low and banks were partly covered in dense vegetation. The open water in the ponds in the floodplain will also have contained fish, as is confirmed by the find of a small fish tooth in the floodplain samples, and may also have provided open water for waterfowl.[4]

River banks and sand dunes | The dense vegetation of stream channels and ponds described above will partly have consisted of communities within the *Phragmition*. Especially along the main channel, however, riparian forest types will have been abundant, with several willow species dominating the tree layer.

It is, nonetheless, partly due to the identification of species from *other* communities that the willow carr can be identified, as no macro-remains of this tree were found. This can be explained by the fact that the undergrowth contains species from a number of other classes identified in the analysis, including the *Bidentetea, Stellarietea, Artemisietea, Phragmitetea, Convolvulo-Filipenduletea* and *Plantaginetea majoris* (Stortelder *et al.* 1999, 167). Willow wood and / or charcoal was identified by Casparie *et al.* (1977) and Van der Laan (2011), and willow pollen is present in all samples studied in the region (Casparie *et al.*

1977; Van der Veen 2008; Maurer 2011). Long-distance import or transport of willow wood is unlikely due to the poor quality of the wood, and its local origin is further confirmed by beaver tooth marks on a number of willow sticks (Casparie *et al*. 1977, 45).

Willow carr vegetation was present along the primary and secondary stream channels (Fig. 3.4). Wet willow forests will also have made up part of the floodplain vegetation (see below).

Figure 3.4 Vegetation types present in the Swifterbant area during the prehistoric habitation period. Clockwise from top left: (1) river bank vegetation showing zonation from reed *(Phragmites australis)* to nettle *(Urtica dioica)* (Vennebroek, The Netherlands, August 2012); (2) alder carr (Nietap, The Netherlands, June 2012); (3) willow carr (Millingerwaard , The Netherlands, July 2013; (4) shallow water vegetation with water plantain *(Alisma plantago-aquatica)* and spike-rush *(Eleocharis)*(Appelscha, The Netherlands, May 2012)

Other tree species, such as alder and birch, will have occurred only occasionally in this vegetation (Rodwell 1998a, 65).

Where willow carr and reed communities (*Phragmition*) were absent (either through erosion or clearance by humans) and nutrient-rich litter and fresh sediment was deposited, pioneer vegetation dominated by such species as *Persicaria hydropiper* (water pepper) and *Bidens* (beggarticks) appeared. Along the sand dunes, a more shade-tolerant association within the *Bidention* was present. The shade was probably primarily caused by the presence of oak trees (*Quercus*), as shown by the acorns frequently encountered in the S25 sieve residues and other finds of

acorns and leaves of oaks surrounding the dunes (Casparie *et al.* 1977, 42). The exact composition of the 'oak forest' on the dunes cannot be identified, but oaks frequently occur in plant communities within the *Alno-Padion*. These forest types grow on drier soils than a willow carr. Although Van Zeist and Palfenier-Vegter are probably right that *Alno-Padion* forests will have occurred on higher parts of the river banks (1981, 135), similar woodland with higher percentages of oak may have been present on the sand dunes. Vissinga's (2007, 23) corings at the river dune in the vicinity of sites S21–S25 yielded large pieces of wood, not unlike those documented for S25 by Geuverink *et al.* (2009, 11). De Moor *et al.* (2009, 69) suggest a regional picture of a mixed oak forest. The suffix -etum in this so-called *Quercetum mixtum* suggests an association, but it is actually a palynological umbrella term for Atlantic forests in low-altitude areas dominated by *Quercus* and accompanied by *Tilia*, *Ulmus* and *Betula* trees. Within modern syntaxonomy, these can be assigned in the Netherlands to the *Quercetea robori-petraea* and the *Querco-Fagetea*, which includes the *Alno-Padion*. As such, we can assign part of what De Moor *et al.* (2009) describe as mixed oak forest to the sand dunes, which fits their interpretation as regional vegetation. The comparison with the study by De Moor *et al.* (2009) is restricted to their section VII, which deals with the infilling of a 'gully' probably connected to the Swifterbant system. Wet grassland communities will have been present on the river banks in the vicinity of the settlement sites.

Exploitation of river banks and sand dunes | The analysis of wood from S3, S4 and S25 shows a strong dominance of alder, irrespective of its use (Casparie *et al.* 1977; Schepers and Bottema in prep.; Van der Laan 2011). Casparie *et al.* are probably right in their claim that this points to an abundant availability of alder, rather than a preference for this species. Although oaks were present on the dunes, they were apparently not common enough to merit or reflect intensive exploitation. Some further remarks regarding the woodland vegetation are made below, but for the more general or cultural overview of wood collecting strategies the reader is referred to Out (2009a, 2010a). Along the primary stream channel, willow carr must have dominated the river

banks. De Roever (2004, 10) suggests the higher river bank of S2 as a one of the possible locations for the *Alno-Padion* forest. This forest provided food plants such as brambles and wild apple, partly also present in the alder carr in the back swamps.

The identified grassland communities will only persist under a grazing regime. Great parts of the river banks must have been used for this purpose, as is also supported by coprophilous fungi from the settlement layer at S4 (Van der Veen 2008).[5] Grassland vegetation, and more specifically *grass* in grassland vegetation, is characterized by the ability to adapt to grazing by spreading vegetatively and by the presence of meristeme tissue close to the soil. Grasslands can therefore be underrepresented in the archaeobotanical record (Woldring and Kleine 2008, 266). The river banks were also used for cereal cultivation (see cereal cultivation below).

The high number of burnt cereal remains and hazelnut shells recovered also confirm that the river banks were used intensively. The absence of acorns at S3 and S4 suggests that, despite the fact that this is theoretically possible, acorns were not used for human consumption – which tallies with Out's (2009a, 347) view on the subject.

Pioneer communities are indicative of disturbance. The identification and interpretation of arable weed communities and other synanthropic vegetation types have long been a matter of debate in archaeobotany (e.g. Bogaard *et al*. 2010; Eggers 1979; Hillman 1991; Knörzer 1971; Kreuz and Schäfer 2011). The decision to only exclude vegetation types if species are missing that would normally be present in over 95% of the present-day relevés of that type causes a number of associations within the arable weed class to be accepted. The absence of typical arable weed species, such as *Thlaspi arvense* and *Fallopia convolvulus,* would have led to an exclusion of more syntaxa if this arbitrary percentage had been set lower. A number of the S3 samples evidently reflect a species combination that fits within the *Stellarietea*, but lack some of the species quite common in the *Bidention*. Since the S3 material shows excellent preservation, this can only be regarded as reflecting past realities. Many species within the *Bidention* show a strong overlap with more anthro-

pogenically influenced plant communities within the *Stellari-etea* and *Artemisietea*. Therefore, species of the *Bidention* are sometimes mistaken as indicators of human disturbance (Van Beurden 2008, 22). The present analysis shows, however, that plant communities within the latter classes are most strongly represented where they are expected: at settlement sites. The 'natural' pioneer communities within the *Bidention* were abundant along the banks under the willow carr vegetation.

It should be emphasized that there is very little evidence for intensive use of the dunes. Evidence for both oak wood and acorns is scarce, and the undergrowth of the more closed canopy at these dunes, as confirmed by the shade-tolerant *Bidention* vegetation, will not have provided the abundant biomass of the more open areas in other parts. The sandy subsoil will also have made the dunes less attractive for cereal cultivation in comparison with the nutrient-rich river banks, despite the certainty that flooding would not occur.

Back swamps | The back swamps are the relatively low-lying parts of the floodplain behind the river banks, which will flood when the water level in the gully exceeds bank height, or when the banks are breached during crevasse splay formation. While no excavations took place in back swamp areas, it is important to try to reconstruct the vegetation in these areas as well, because its distribution affects exploitation possibilities.

Extensive coring projects for the adjacent floodplain were published by Nales (2010) and at a greater distance from the river system by Coppens (2009). Nales's research shows that the floodplain levels contemporaneous with the Swifterbant habitation have suffered from substantial erosion. Some remarks can, however, still be made. The back swamps consisted of both clay and peat. When the back swamps flooded, new clay was deposited in the area, which will subsequently have been colonized by reed. At some places, this reed vegetation was able to develop into peat layers; at other localities ongoing clay sedimentation resulted in what Ente (1976, 19) describes as 'soft back swamp deposits', which are relatively rich in organic matter. Whereas Coppens found exlusively reed- or sedge-peat, Nales presents a

more diverse picture, with some corings yielding wood remains, and others containing almost exclusively reed or unidentified root fragments. This is a direct result of the fact that the research done by Nales is much closer to the river system. Sampling of the top of the peat where it was not eroded confirmed the existence of open water in the floodplain, in the form of high numbers of *Cladium mariscus* as well as *Daphnia* and *Chara* species (appendix 3a-c). One find of a foraminifera shell indicates incidental flooding with brackish water. The presence of open water is also indicated by soft back swamp clay deposits containing only a few plant remains.

Combining these observations, it appears that the floodplain in the Swifterbant area consisted of a mosaic of open water and reed / sedge swamps. Several wet woodland types will have been present here and there, mainly along the river banks and river dunes. De Moor *et al.* (2009, 69–71) studied sediments from a 'creek' fill probably connected to the Swifterbant system. Based on the study of both pollen and macro-remains, they identified the local vegetation as alder carr, reed swamps and Great fen-sedge swamp. Their reconstructed local vegetation fits well within the overall ecological characterization of the region, but undervalues the woodland diversity. The presence of alder carr (Fig. 3.4) on the transition between river banks and back swamps, as suggested by Van Zeist and Palfenier-Vegter (1981, 139), holds true for the more inland parts of the system, but near the main channel and more towards the west, willow carr will have dominated. The ongoing deposition of nutrient-rich sediment (Grootjans *et al.* 2012, 206) along most of the river banks will have been better suited to the development of willow carr, resulting in a riparian forest. Alder carr will have been absent along the main channel, and should instead be located in the less dynamic parts of the floodplain and cut-off river channels. This will still have covered substantial areas.

Exploitation of back swamps | The exploitation of the back swamps has partly been dealt with in the section titled 'Stream channels and ponds'. The open water will have been suitable for fishing and fowling, whereas the edge of the alder carr provided a rich

variety of possible plant food sources, such as *Humulus lupulus* (hop), *Rubus fruticosus* (bramble) and *Crataegus monogyna* (hawthorn).

DISCUSSION | Actualism | In the paper that introduces the PALAEOASSOCIA method (Schepers *et al*. 2013), a whole paragraph is devoted to the validity of using present-day plant communities to reconstruct past vegetation. In the introduction to that paper, the alternative approaches to vegetation reconstruction are also dealt with at length. As Bakels and Zeiler point out, 'the wet part of the Netherlands was […] a mosaic of different kinds of vegetation' (2005, 311). By using the most detailed approach possible, the present analysis aims to sharpen the resolution of our view on this mosaic, leading to much more detail than can be achieved by using ecological groups, such as 'ruderal species' or 'marsh plants'. It would be 'safer' to restrict the syntaxonomic depth to the class or alliance level, but these levels do not facilitate detailed visualization and hamper a thorough insight into the possible exploitation by man. Moreover, the analysis suggests multiple possible plant communities for most groups, which are all taken into consideration in the interpretation.

Salinity | A number of proxies indicate an open coast and an incidental influx of brackish or saline water. First, the formation of the river banks themselves at Swifterbant is a direct result of the mixture of fresh and brackish water (see 'Introduction: Geomorphology'). According to analyses conducted by De Wolf and Cleveringa (2005, 2006, 2009a, 2009b), the frequent presence of coastal diatoms testifies to a clear but incidental coastal influence. Their analysis of the diatoms took into account not only the ecological specifics of the diatom species recovered, but also the fragmentation of the diatoms (cf. methodology of Vos and De Wolf [1988]). The large number of broken shells from marine species enabled De Wolf and Cleveringa to differentiate between autochthonous and allochthonous species, labelling the marine diatoms as 'coastal allochtones'. Related to this, the foraminifera found in several palynological spectra confirm an incidental marine influence (Van der Veen 2008, 5).

Second, Van Zeist and Palfenier-Vegter (1981, 140) have already pointed out that the presence of Aster tripolium, Juncus gerardii and Salicornia europaea in the samples suggests a marine influence, but that the overall plant evidence does not suggest that the area was more or less regularly flooded with brackish water. The salinity ratio, calculated from a selection of halophytes and glycophytes as proposed by Behre, would result in a 33.3 ratio, which cannot be right given the overall picture (1991, 159–160). As was pointed out by Brinkkemper, the fact that Behre's system is based on presence/absence at the site level may have caused this effect (1993, 102). Salicornea europaea (s.l.) is ruled out completely as not fitting the overall Swifterbant ecology by the present analysis, because it is bound to high salinity values, although Meltzer and Westhoff (1942, 238) mention that it occurred under brackish conditions in the former Zuiderzee. The poor physical preservation of the S. europaea seeds from the Swifterbant samples seems to confirm long-distance transport. The characteristic hairs, formed by elongated cells of the outer integument, have eroded (Shepherd *et al.* 2005, 923). Analogous to the broken diatom scales, these seeds can be labelled coastal allochtones (Fig. 3.5). However, the only two finds of Salicornea europaea in the area originate from the deepest levels. These seeds may therefore also be considered a faint signal of a pioneer stage in the river bank vegetation. Their position directly beneath the cereal field at S4 would then indicate a rapid desalinization of the river banks. Although no present-day Dutch vegetation type in direct succession of Salicornia-dominated vegetation was identified in the analysis, it is worth mentioning that a basal community dominated by a more salt-tolerant variety of Bolboschoenus maritimus (var. compactus, Weeda *et al.* 2003b, 249) can occur in succession of a Salicornietum, as is quite common in the Dutch and Belgium Scheldt estuary (Beeftink 1965, 123–124; Vandenbussche *et al.* 2002, 58–62). The more salt-tolerant variety of B. maritimus cannot be distinguished archaeologically from the fresh to brackish form (var. maritimus). Juncus gerardii and Aster tripolium are predominantly coastal species today and will have been so in the past. They can also occur in fresh environments and will have been present in the

Swifterbant river system (Van der Meijden 2005, 137–138, 593; see also Hogestijn 1989, 121).
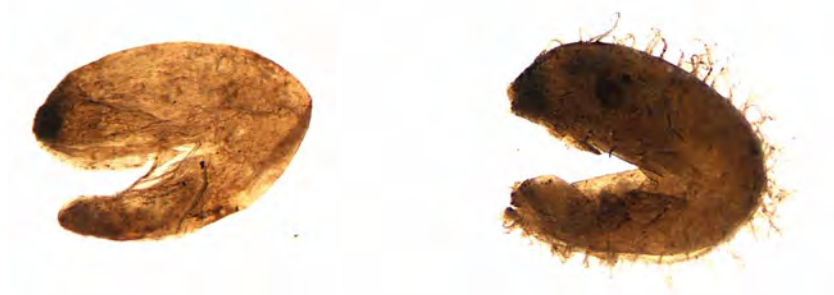
Figure 3.5 Subfossil seeds of *Salicornia europaea* from Swifterbant (left) and Heveskesklooster, province of Groningen, the Netherlands, iron age terp (right). The hairs that are present on the Heveskesklooster specimen have eroded on that from Swifterbant

The third and final proxy for landscape conditions are the stable isotope investigations on human bones from the area. These show δ13C and δ15N values consistent with a strong aquatic component, but lacking a strong marine signal when compared with some other Dutch wetland sites (Smits and Van der Plicht 2009, 79). In accordance with the interpretation by Van Zeist and Palfenier-Vegter (1981), a brackish influence must have been present only incidentally, for example, during seasonal storms, and saline influx would have affected the main channel in particular. The overall nature of the Swifterbant river system ecology is therefore best described as a freshwater riparian system. In contrast, the historic Zuiderzee, whose tidal inlet lay along its northern edge (the present-day Wadden Sea), was brackish and locally even saline (Hogestijn 1989; Jansen and Wachter 1930; Van Goor 1922).

Floodplain fens and peat formation | At Swifterbant, several plant communities have been identified that can be related to peat formation (indicated with a '(p)' in Table 3.2). Although there has been some debate on proper terminology relating to peat ecology (e.g. Wheeler and Proctor 2000; Joosten and Clarke 2002), some consensus has been reached. A peatland where peat is currently

being formed is labelled a mire. Mires can be divided into ombotrophic acidic bogs (rainwater-fed) and rheotrophic neutral to base-rich fens (ground- or surface water–fed; Grootjans *et al.* 2012, 204; Wetzel 2001, 820). In Dutch geology and archaeology, peat development is commonly illustrated by referring to Visscher (1949, 44, fig. 6), schematically showing the relationship between vegetation types involved in peat formation and the peat types produced by these types (e.g. Berendsen 2004, 228; Van Asselen and Bos 2009, 59). This simplified scheme applies specifically to the terrestrialization of depressions containing open water, such as pingo scars. This terrestrialization process has long been known to progress via a more or less standard vegetation succession, the hydrosere (Wheeler and Proctor 2000, 190), as is also shown by Visscher (1949). In the current vegetation succession analysis, starting from open water, all successive communities related to rheotrophic peat formation have been identified (Table 3.2), including reed swamps, sedge swamps and alder carr communities. Whether or not a plant community is related to peat formation is based upon a comparison of the identified plant communities with the publications mentioned above. In other words, although the Swifterbant system is not a closed water body, such as a pingo scar or a small lake, all stages of rheotropic peat development existed simultaneously over the area during the habitation period. Because the Swifterbant back swamps are part of a floodplain, the development of large-scale oligotrophic (nutrient-poor) bogs is not very likely. Intensive flooding in winter and spring, depositing fresh silt and clay sediments, will increase the nutrient availability (Grootjans *et al.* 2012, 206). Bogs nonetheless did develop at a greater distance from the stream channels (Brinkkemper *et al.* 2009, 56). The thus created picture of the distribution of fens and bogs is confirmed by the distribution of Sphagnum peat in the maps presented by Peeters (2007, 64–71, fig. 3.12) and corings in and near the floodplain (Coppens 2009; Nales 2010). Bogs can develop in open coastal systems, as shown by research in the Scheldt estuary (Deforce 2011), but this requires a different geomorphology. Peat moss spores and leaves are commonly found in the Swifterbant region (e.g. Van der Linden 2008; Van Zeist and Palfenier-Vegter 1981; Weijdema

et al. 2011). These plant remains can therefore be interpreted as the result of long-distance transport or as a signal of incidental meso- or oligotrophic patches that commonly occur in predominantly eutrophic fenland areas (e.g. Rintjema *et al.* 2001, 99–100).

Periodic occupation | Whether or not the habitation at the Swifterbant river bank sites was periodic has been discussed repeatedly (e.g. Raemaekers 1999, 41–42; Louwe Kooijmans 1993, 90–94; Zeiler 1986, 1997, 86–87). Plant communities within the *Bidention* as well as the *Salicion* confirm the hypothesis that large parts of the river banks must have flooded in winter time, because these pioneer plant communities consist for a large part of communities that grow on newly deposited sediment. In the summer season, wet *Bidention* communities can even occur in river beds that have fallen dry. In different spits of the S3 samples, a hint of this process is visible in the data. In the deepest spit, spit 9, aquatic communities are amongst the suggested syntaxa for 4 out of 6 samples. One spit higher this has fallen to 1 out of 9, after which it climbs again, to 4 out of 6 in level 6 (Fig. 3.6). The samples most likely show periodic flooding of the river bank, which resulted in the deposition of seeds from aquatic plants as well. Seed density was used as a criterion for which samples to analyze at S3. The strategy to focus on more 'seed-rich' samples will have caused an overrepresentation of pioneer vegetation. There is a good chance that the process described here would have been identified more convincingly had more – and more random or landscape-determined – samples been analyzed, among which samples with few seeds. The fact that flooding took place between habitation phases is also shown by the diatom analysis of the S4 settlement layers (De Wolf and Cleveringa 2005). Diatoms from a vertical section of settlement layers showed that the relative presence of marine diatoms fluctuates in comparison with the aerophilous species, although marine species are constantly present. The lithology of the Swifterbant river banks is also indicative of an occasional mixture of fresh and brackish water (see discussion: Salinity). Had saline marine influx occurred daily, as opposed to seasonally, the overall ecology would have been considerably more brackish.

In summary, all palaeolandscape proxies indicate periodic flood-ing of the river banks, in line with the early findings of Ente on this matter (1976, 32). The strong representation of plant com-munities within the *Bidention* suggests this process must have repeated itself over and over again over the years (see discussion: Time-depth). Whether or not this happened *every* year cannot be reconstructed. All these data add up to the simple field observa-tion that relatively clean clay layers alternate with 'finds layers', thus testifying to ongoing sedimentation during the formation of the cultural layer (De Roever 2004, 21).
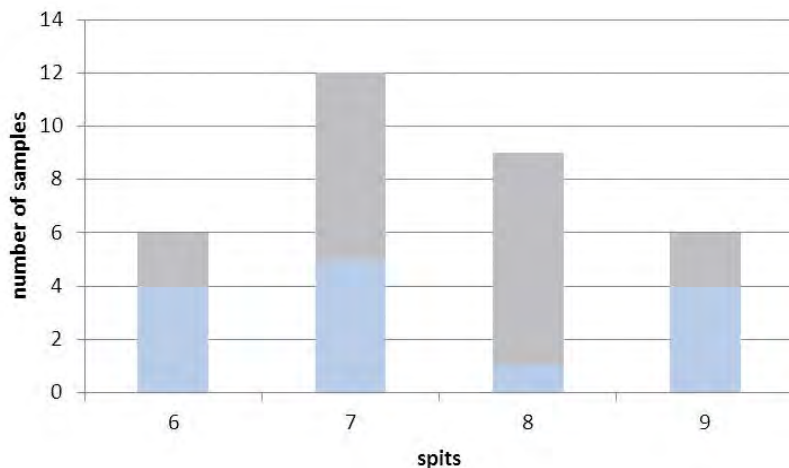
Figure 3.6 Number of samples for which a wet community is among the suggestions in the palaeo-associa analysis for spits 6–9 of Swifterbant site S3. Blue represents samples with wet communities, grey represents samples lacking wet communities. Layer 9 is the oldest/deepest. Because the four deepest spits represent 33 out of 46 samples, the top 5 spits have not been shown here. Note that wetter (6, 9), mixed (7) and drier (8) episodes alternate

Peeters' (2007, 206) suggestion that these floods mainly oc-curred during a first phase of occupation is not supported by eco-archaeological data. Zeiler's suggestion that some years may have been more favourable for year-round occupation cannot be dismissed outright, but it seems improbable. The suitability of river banks for hunting and fowling during wetter times, how-ever, was high (Zeiler 1997, 87). Isotope evidence from human remains seems to point to seasonal utilization of upland terri-tory (Smits and van der Plicht 1999, 79–80).

Time depth | Like Van Zeist and Palfenier-Vegter's earlier (1981) landscape reconstruction, the present interpretation pays little attention to developments over time, primarily because the radiocarbon calibration curve shows a plateau for the period of Swifterbant habitation (Reimer *et al.* 2009). Nonetheless, the numerous finds of anthropogenic indicators in all levels sampled by Van Zeist, including cereal grains (depicted in Neef *et al.* 2012, 409), justify linking the vegetation reconstruction with the period of human exploitation. Two of the S4 drift litter samples were taken at a level higher than the lowest archaeological levels analyzed by Van Zeist and Palfenier-Vegter located along the same stream channel. Apparently, the top of the river bank had silted up to such an extent that drift litter washed ashore at a higher level than the oldest occupation phases. These oldest occupation phases were also located on the top of the river bank, but this was considerably lower by then. This once again confirms the ongoing silting up of the river banks. These samples from higher up in the sequence can also be related to a human occupation phase, as is shown by the recovery of both artefacts and barley rachis fragments (depicted in Cappers and Neef 2012, 285). The analysis of the S3 settlement levels shows the ongoing dominance of pioneer vegetation. Human disturbance also prevented natural succession. There are indications of an initial colonization of the river banks by *Salicornia*-dominated vegetation at the first formation of the river banks, at S3, but these are very weak. Brackish influences were very low from the very start of habitation until the last phases studied archaeobotanically (see discussion: Salinity). The identification of an Emmer wheat spikelet fork, dating to about 500 years after the abandonment of the river bank sites in the direct vicinity, suggests that exploitation of the landscape remained possible at a relatively short distance (De Moor *et al.* 2009, 70).

Cereal cultivation | The discussion about whether or not cereal cultivation was practiced locally has become somewhat moot with the discovery of a tilled field in the S4 excavations (Huisman *et al.* 2009; Raemaekers in prep.a). Nonetheless, the results of the present study enhance our insight into the past environment and hence contribute to our understanding of this cultivation.

The strong presence of, in particular, ruderal communities and weed communities in the S3 settlement samples confirm large-scale vegetation disturbance, which may have included cultivation. A comprehensive discussion of Neolithic crop husbandry practices is presented by Bogaard (2004), who later argued that the species mentioned as potential arable weeds by Cappers and Raemaekers (2008) are generalists, and therefore not convincing indicators for cultivation (Bogaard 2008). The present analysis shows that the *combination* of 'generalist' species found in some of the settlement samples clearly points to arable weed communities. These weed communities lack some characteristic species, but this is to be expected when cereals are cultivated in a landscape where no cultivation is practised nowadays. Farming in an environment where no or little farming is practiced nowadays will lead to non-analogous plant communities. In other words, at Swifterbant, and probably at other wetland sites in prehistory, there will have been a weed community resembling the *Stellarietea* communities, consisting for a large part of species it shares with the *Bidention*, but lacking the 'wetter' species therein. The absence of cereal remains, in combination with the fact that no association from the *Stellarietea mediae* was identified at S25, strengthens the interpretation that cereal cultivation was restricted to the river banks.

The Swifterbant system cannot be compared with any big river floodplain in central Europe, since no upland dry soils are available in the direct vicinity of the Swifterbant sites except for the dunes. It should also be mentioned that riparian vegetation is not at all uniform, but instead dependent on a number of factors, of which stream size, in particular, is relevant to the Swifterbant situation (Dybkjær *et al*. 2011). It is also questionable to speak of 'evidence for crop cultivation at sites of the Swifterbant culture' (Deforce *et al*. 2013, 58). Such claims need to be evaluated per site, or at most, by region (as was done by Out [2009a, 179]). A combination of (a) the arable weed (associations) evidence, (b) the cereal fragments recovered, and (c) the cultivated field itself proves cereals were grown on the river banks in the direct vicinity of the Swifterbant settlements. It should again be stressed (per Cappers and Raemaekers 2008, 392–393) that this will have been cultivation on a very modest scale.

CONCLUSIONS I This paper presents a detailed reconstruction of the vegetation and related exploitation possibilities of the Swifterbant river system on a plant association level. Bakels and Zeiler eloquently describe the area as a vast swamp transected by creeks (2005, 316). This characterization slightly undervalues the role of the river system as the key component of the landscape in favour of the back swamps. As far as the big picture is concerned, the interpretation published by Van Zeist and Palfenier-Vegter (1981) is found to be mostly correct. The inclusion of data from additional sites that were not available to those authors, together with the application of new methodology, has, however, significantly enhanced our understanding of the Swifterbant river system as a whole and has also made it possible to compile a more detailed image. The high biomass would have accommodated a wide variety of food sources for humans, as well as grazing for livestock.

Notes

1 The aim here is to end the discussion on the geomorphological description of the system. Because of the fact that the tidal difference must have been very limited (~15 cm), the term tidal is rejected in this context. The waterways themselves are referred to as (stream) channels, following Bradshaw and Weaver (1995, 250). By using the term 'river system' rather than 'creek system', the significance of the connection with the river IJssel as well as the differences with coastal creeks are emphasized. Thus insights from this study are combined with points brought forward by dr. Kim Cohen and Peter Vos at the 2012 Dutch archaeology convention (Reuvensdagen).

2 It concerns the following species and syntaxon codes: Hippuris vulgaris (08Aa1); Cicuta virrosa (08Ba2a); Thelypteris palustris (08Bb4d); Juncus maritimus (26Ac7); Fallopia convolvulus (30Aa2, 30aa1a, 30Bb1b); Echinochloa crus-galli (30Bb2a); Urtica urens (31Ab1b, 31ab1c) and Rubus caesius (43Aa3b).

3 The chances of species-poor communities being 'hidden' behind other communities is a problem well known in archaeobotany. In the salt marsh area, for example, Behre describes the poor visibility of the Juncetum gerardii typicum in relation to the more species-rich subassociation J.g.leontodontetosum (Behre 1976, 31).

4 Probably Cyprinidae species, kindly looked at by Lisette de Vries.

5 Bas van Geel kindly provided help with the identification of coprophilous fungi.

APPENDICES TO CHAPTER 3 RESULTS OF THE MACROFOSSIL ANALYSIS OF THE TOP OF THE PEAT IN THE BACK SWAMPS

Taxon	Plant part	Coring number					
		202	22	197	94	13	29
Not identified	wood	x					
Lophopus chrystallinus	statoblast	x					
Daphnia	ephippium	x	x				
cf. Cyprinidae	tooth		x				
Foraminifera	lining		x				
Humulus lupulus	fruit		x				
Typha	fruit		x				
Lythrum salicaria	seed		x		x		
Atriplex patula/prostrata	fruit			x			
Chara	oospore		x		x		
Cladium mariscus	fruit with exocarp			xx			
Sphagnum	leaf	x	x	x	x	x	
Alnus	wood			x	x		
Carex pseudocyperus	utricle		x		xx	x	
Cladium mariscus	fruit		x	x	x	x	x
Schoenoplectus tabernaemontani	fruit		x				x
Comarum palustre	fruit				x		
Berula/Cicuta/Apium	fruit				x		
Alnus glutinosa	fruit		x		x		x
Oenanthe aquatica	fruit				x		
Betula	fruit					x	
Callitriche	fruit					x	
Apiaceae	fruit					x	
Alnus glutinosa	cone					x	
Urtica dioica	fruit					x	
Alisma	fruit					x	x
Hydrocotyle vulgaris	fruit						x
Lycopus europaeus	fruit						x

Mentha aquatica/arvensis	fruit	x
Ranunculus subg. batrachium	fruit	x
Bolboschoenus maritimus	fruit	x
Not identified	charred wood	x

Appendix 3A macro-remains from the top of the peat in the back swamps. The data presented are arranged by seriation, using PAST (Hammer *et al.* 2001). x=present; xx=many

Coring number	top	bottom	volume
13	195	215	140
22	210	230	140
94	135	160	175
197	160	180	140
202	200	220	140
29	165	180	105

Appendix 3B Volume and depth below surface of the samples. At all locations, we sampled the top of the intact peat. The presented volume is based on the not completely correct assumption that a perfect round cylinder was sampled out of a 3cm soil auger ($\pi r^2 = \sim 7$, 7*height=volume)

Coring number	X	Y	Z
13	171994	509754	-4,5
22	171502	509659	-4,5
94	171418	509744	-4,7
197	171614	509940	-4,7
202	171808	509991	-4,6
29	171773	509731	-4,6

Appendix 3C Location of the corings (Dutch grid). The location of the corings is extracted from Nales (2010). The reader is referred to this report for a description of the lithology. We relocated the corings with a handheld Garmin Etrex GPS. This device is less accurate than the original measurements, which may explain some of the difference in depth of the peat layer

Box 2 | 109

Why sample ditches?

Schepers, M.

ABSTRACT | The ambition of palaeobotanists and archaeobotanists to reconstruct vegetation outside of actual settlements has a long history. In coastal areas, where no nearby lakes or pingo scars containing long sequences of chronologically laminated sediments exist, this information needs to be gathered from other contexts. Where pure samples are absent or found not to represent the section of the vegetation being targeted, natural or anthropogenic ditches at greater distance from a settlement context may be helpful. Research on these ditches may shed light on the degree of anthropogenic activity farther away from the settlement, allowing a better insight into a wider human impact on the landscape.

In this box, two case studies dealing with exactly this type of context are presented, one being a ditch along a presumed crop field in a reclaimed peat bog, the other being a natural creek running through a salt-marsh landscape. The results certainly help in understanding the past landscape, but several methodological problems remain with respect to the reconstruction of vegetation.

KEYWORDS | Ditches · Mixed assemblages · Taphonomy · Salt marsh · Peat bog · Arable weed vegetation

INTRODUCTION | In archaeology, natural and anthropogenic linear features originally containing running water, such as creeks, ditches, rivers, or channels, are among the most frequently sampled types of contexts. In the Dutch wetlands, they are of particular interest from a palaeoecological point of view. Despite the implication of the term 'wetland', substantial parts of the landscape will not always be (permanently) wet, thus lacking the ideal circumstances for the preservation of waterlogged plant remains in long vertical sequences. However, the role that channels outside of a settlement can play in the environmental reconstruction of a wetland landscape is as yet not fully appreciated (but see, e.g., O'Connor 1988; Smith *et al*. 2001). The dynamics of 'big rivers' and adjacent floodplains, such as the Rhine and the Danube, are of a considerably different magnitude and therefore not taken into account here (e.g. Cappers 1993; Davies *et al*. 2008). For the remainder of this box, the term 'ditch' is used as an umbrella term for both creeks and ditches.

Many contributions regarding the taphonomy of plant macro-remains focus on settlement features (e.g. Bottema 1984; Cappers 2006; Jacomet 2013; Van der Veen 2007). This is a consequence of a cultural interest in plant exploitation, but also of the simple fact that many excavations barely extend beyond the settlement area. All plant remains recovered from a settlement context are the direct or indirect result of human activity and are therefore 'ecofacts' (Jacomet 2007). An indirect result of human activity influencing the archaeobotanical record is the formation of 'settlement vegetation'. Settlement vegetation is made up of plant species that thrive under a high concentration of minerals – in other words, the types of soils generally available in anthropogenic environments. Plant species growing in a settlement are adapted to disturbance and/or stress typical for pioneer vegetation. Sampling for seeds within a settlement will in many cases result in an overrepresentation of plants that grew in the settlement itself (Cappers 1994; Cappers and Neef 2012, 107–111, 175). Information about the vegetation outside the settlement, therefore, relies heavily on samples from settlement contexts that are believed to contain signals from landscape components outside of the settlement – in other words, reconstruction of off-site patterns through on-site sampling.

Box 2 **111**

Willerding (1991, 36) lists some of these possible sample contexts, such as sods, dung layers, and crop concentrations. These are all studied by various scholars, sometimes with useful results, but due to their complex taphonomy these contexts entail serious interpretation issues. Sods are believed to directly represent part of the original vegetation in the vicinity of a site and are therefore frequently selected for palaeobotanical analysis (e.g. Nieuwhof 2012; Van Geel *et al*. 2003). Especially pollen can be quite well preserved in sods. Dung samples can provide information on grasslands and hay fields, but their taphonomy is very complicated (e.g. Hall and Kenward 1996; Shahack-Gross 2011; Schepers *et al*. 2013a; see also Chapter 4). The recovery of crop concentrations can potentially provide information on arable weed vegetation (e.g. Wilson 1984; Van Zeist 1989; see also Box 1).

Figure B2.1 A narrow ditch in the high salt marsh. The ditch will serve as a trap for all sorts of plant remains because of both its dynamic nature and its permanently waterlogged condition. The Atriplex portulacoïdes shrubs along the ditch testify to minor levee formation (Noordpolderzijl, The Netherlands, July 2010)

Another way to gain information on the environment surrounding the settlement is to actually sample outside the settlement. The need for these types of samples was recently emphasized for

Bronze Age West Frisia (Lohof and Roessingh 2014, 66). Given the profoundly different (that is, wider) dispersal characteristics of pollen, palynology is generally considered best suited to the reconstruction of the natural environment (Kooistra 2002a; Kreuz 1995). Plant macro-remains are generally considered a useful complementary source of information (Birks and Birks 2005; Dieffenbacher-Krall 2007). They generally allow for a more 'local' signal and for the identification of more taxa to a lower taxonomic level. Several studies have analyzed plant macro-remains in addition to pollen (e.g. Bozilova and Beug 1992; De Moor *et al.* 2009; Havinga *et al.* 1992; Regnell *et al.* 2005; Weijdema *et al.* 2011). These studies, however, mainly focus on long vertical sections in undisturbed soils and sediments, which, according to Kooistra (2002a, 8), are a prerequisite for a good result.

As pointed out by Robinson (1992), long organic sequences are not always available. Under these conditions, according to Caseldine, 'palaeoenvironmental analysis relies heavily on "derived" deposits such as the infills of a ditch' (1982, 39). Small channels will often act as a trap for plant remains in the immediate surroundings. The relationship between vegetation and such trapped plant remains is complicated, being dependent upon a number of factors, such as stream size, seed buoyancy, seed production, and hydrodynamics (Boedeltje *et al.* 2003; Chang *et al.* 2008; Holyoak 1984; Thompson *et al.* 1997). The potential relevance of floodplain deposits and old river branches, such as oxbow lakes, for palaeoenvironmental reconstructions is emphasized by Jacomet and Kreutz (1999, 72–73). In this box, however, the focus is on two examples of smaller ditches of profoundly different character, one artificial and one natural. One feature they have in common is that the original associated surface level is hard to distinguish. The potential of both ditches for a more complete understanding of the past off-site environment will be evaluated in the discussion.

SAMPLING AND PROCESSING | Because this box is not about the archaeology of either of the two case studies presented here, no map indicating their position is included. For the exact location of the studied sites, the reader is referred to Figure 1.6 (General introduction).

Box 2 | **113**

Case study 1 | Annelies Vermue (2012) investigated a system of ditches that was originally dug into bog peat soil but is today buried under approximately 1 metre of so-called Dollard clay. Located near the present-day village of Noordbroek, these ditches were discovered through detailed inspection of the LIDAR-based Actueel Hoogtebestand Nederland (height model of The Netherlands) (Fig. B2.2).The Dollard clay layers formed as a consequence of repetitive flooding of the area. Obtaining an exact date for the deposits is complicated, but they probably start around the end of the 13th century AD (Vermue 2012). This serves as a terminus ante quem for the ditch system. The anthropogenic nature of the buried system is beyond doubt, but the exact function of the ditches is still uncertain.
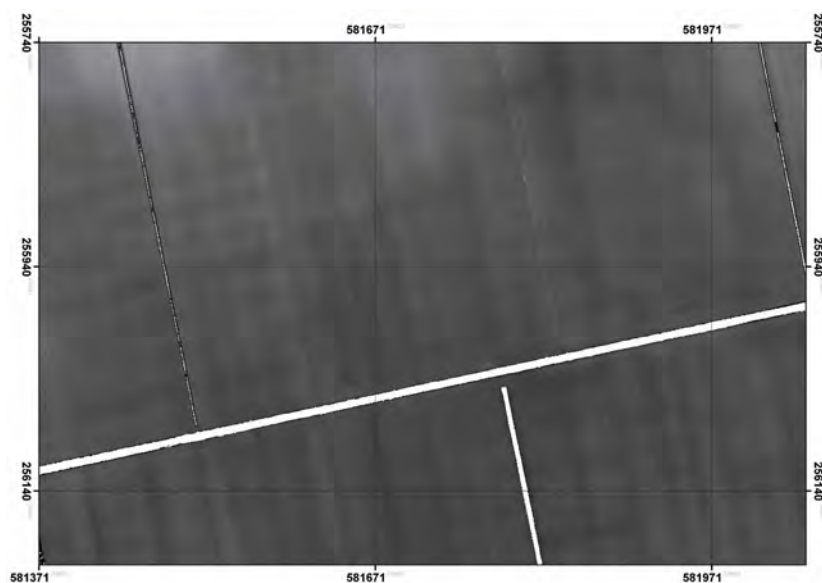
Figure B2.2 The buried ditch system near Noordbroek. In the photo, the faint dark grey ditch pattern is clearly visible. These ditches cannot be witnessed in the field today. The clear white lines are still-extant ditches. Figure by Annelies Vermue

To locate the exact position of one of the ditches, 23 soil cores were taken, using a 3 cm soil auger in a straight line. A basic description of the overlying sediments was made. Soil samples to be scanned for plant macro-remains and pollen were taken from the top of the peat between the ditches. Once the ditch was

detected, a 20 cm auger was used to extract a soil sample from the fill of the ditch.

Case study 2 | During the archaeological work on a series of test trenches near the present-day village of Marssum (Van Benthem 2012), thin organic layers were observed in a faint ditch cut through natural deposits under the cultural layers. These thin organic layers were described in the field as peaty layers. No cultural material was associated with the ditch (or creek). It was therefore believed to possibly hold a signal of the vegetation surrounding a ditch running through the past (semi-)natural salt marsh – in other words, free of anthropogenic settlement noise. The ditch was sampled using a metal sampling container, allowing for more precise sampling in the laboratory. The sampling container is 50 cm in height and 10 cm in both depth and width.

Processing | The soil samples were sieved following standard procedures, and the residue was analyzed for the presence of plant macro-remains. The macro-remains were identified to the lowest possible taxonomic level. A pollen sample of the peat from case study 1 was prepared according to Faegri and Iversen (1989). The sample was scanned by Arnoud Maurer (EARTH Integrated Archaeology) for anthropogenic indicators (more specifically, crops) that may relate to the exploitation of the top layer above the peat.

RESULTS | Case study 1 | Fig. B2.3 is an idealized section based on the soil cores. The Dollard clay on top of the ditch system was divided in two layers (layers 1 and 2), one being the present plough zone (layer 1). No indication of older vegetation levels in the clay were found below the present plough soil. The top of the peat appeared degraded in most of the cores (layer 6). It could not be determined whether the top of the peat represented a former arable level. The fill of the ditch consisted of clay. It could easily be distinguished from the overlying sediments by its colour and its texture. Two layers could also be distinguished in the ditch fill (layer 3 and 4). These two layers are primarily the result of modern-day fluctuations in the groundwater level. The reddish

Box 2|**115**

discoloration of the uppermost ditch fill (layer 3 in Fig. B2.3) is probably the result of oxidation of iron-containing components. The degradation of the peat, as mentioned above, may very well be a consequence of these fluctuating groundwater levels as well.
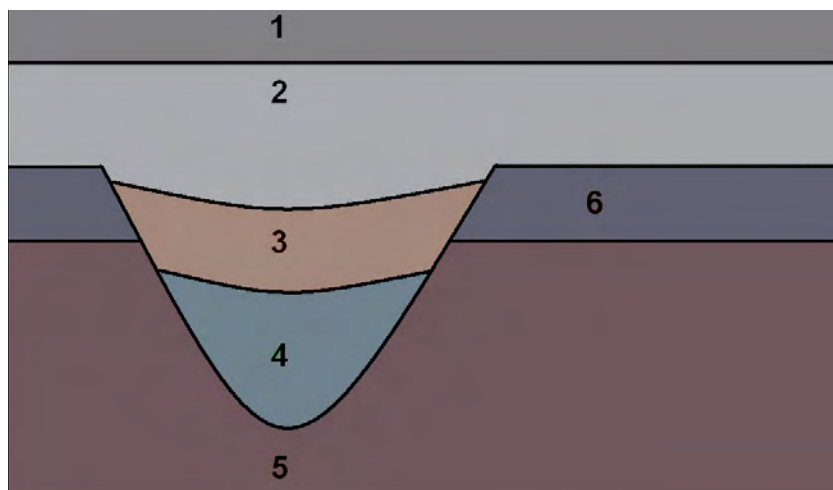
Figure B2.3 Idealized section through the Noordbroek ditch system. 1=modern-day arable layer (clay); 2=clay sediments; 3=upper ditch fill, differing in colour because of fluctuating groundwater levels (clay); 4=permanently wet ditch fill (clay); 5=intact peat; 6=peat degraded through dehydration. The thickness of layers 1 and 2 combined is approximately 1 metre

The pollen scan of the top of the peat did not result in the identification of anything that could be related to the exploitation of the peat. The top of the peat probably dates to the Subatlantic period. The recovered macro-remains represent typical bog plants, such as *Andromeda polifolia*, *Erica tetralix*, *Rhynchospora*, and *Sphagnum*.

The primary fill of the ditch (layer 4) tells a different story (Table B2.1). Dominated by extremely well preserved remains of arable weed vegetation, it clearly points to agricultural exploitation of the surrounding area.

Notable species are *Thlaspi arvense* and *Fallopia convolvulus*. Three other ecological groups are represented in lower numbers. Besides vegetation that will have grown in and along the ditches (represented by *Potamogeton* and *Callitriche*), the fill also included the remains of bog plants, which are probably related to erosion of the exposed peat on both sides of the ditch.

Minor indicators for a salt marsh signal are represented by *Triglochin maritima* and *Aster tripolium*. Although *Bolboschoenus maritimus* is also categorized in this group, it may very well have grown along the ditches as well. The physical appearance of the single find of *Triglochin maritima* indicates it must have been subject to dynamic conditions and was probably transported over a great distance. The seed had already gone; only the torn fruit wall remained.

It is not the purpose of this box to reconstruct the crop cultivation in the area, but I should mention something rather odd: no remains of a possible associated crop were found initially. Only from the last portion of the sample was one fruit of Hemp (*Cannabis sativa*) retrieved. More research would have to confirm whether this was indeed the only crop that was cultivated.

Case study 2 | Eight different layers were distinguished, which can be divided into the following three main groups: pure clay layers, clay with sandy sublayers, and layers with organic sublayers (Fig. B2.4 and table B2.1). It is admitted that this division is to some extent arbitrary, but it was chosen as a good balance between being accurate and avoiding ending up with a very high number of very thin layers. Layers 1 and 7 consist primarily of clay (group 1). In layers 3, 5, and 8, this clay is also present, but, in addition, a number of sand layers can be distinguished (group 2). The heavier sand particles testify to stronger floods, capable of carrying the heavier (bigger) sand particles and all kinds of plant diaspores. The organic layers that triggered the sampling are labelled 2, 4, and 6 (group 3). Their presence indicates that vegetation developed in the vicinity of the ditch between periods of heavy flooding.

Taxon	Plant part	Abundance	Ecological group
Cannabis sativa	fruit	1	Crops
Atriplex patula/prostrata	fruit	4	Arable weed
Carex hirta	fruit	3	Arable weed
cf. Centaurea cyanus	fruit	1	Arable weed
Cirsium/carduus	fruit	4	Arable weed

Box 2 | **117**

Fallopia convolvulus	fruit	3	Arable weed
Fumaria officinalis	fruit	2	Arable weed
Galium aparine	fruit	1	Arable weed
Lamium amplexicaule	fruit	2	Arable weed
Leontodon	fruit	1	Arable weed
Myosotis	fruit	3	Arable weed
Persicaria hydropiper	fruit	1	Arable weed
Persicaria lapathifolia	fruit	1	Arable weed
Polygonum aviculare	fruit	3	Arable weed
Ranunculus acris/repens	fruit	3	Arable weed
Raphanus raphanistrum	seed	1	Arable weed
Sagina	seed	1	Arable weed
Sonchus arvensis	fruit	1	Arable weed
Sonchus asper	fruit	3	Arable weed
Stellaria media	seed	3	Arable weed
Thlaspi arvense	seed	4	Arable weed
Viola	seed	1	Arable weed
Callitriche	fruit	1	Water
Potamogeton cf. natans	fruit	1	Water
Ranunculus subg. Batrachium	fruit	1	Water
Rumex cf. hydrolapathum	fruit	2	Water
Calluna vulgaris	leaf	1	Bogs and mires
Erica tetralix	leaf	3	Bogs and mires
Rhynchospora	fruit	1	Bogs and mires
Sphagnum	leaf	4	Bogs and mires
Aster tripolium	fruit	1	Salt marsh
Bolboschoenus maritimus	fruit	1	Salt marsh
Triglochin maritima	fruit	1	Salt marsh

Table B2.1 Plant macro-remains from case study 1 identified in layer 4 (see Figure B2.1). Ecological groups are self-defined. Abundance categories: 1=1 or 2; 2=3–~10; 3=~10; 4=numerous

The division into three categories having been made, it was decided to study one layer from each category. For practical reasons, it was decided to select the top three layers (layers 8, 7, and

6). A low density of remains was expected in both layer 8 and layer 7, whereas layer 6 was expected to contain a signal of salt marsh vegetation outside of a settlement context.
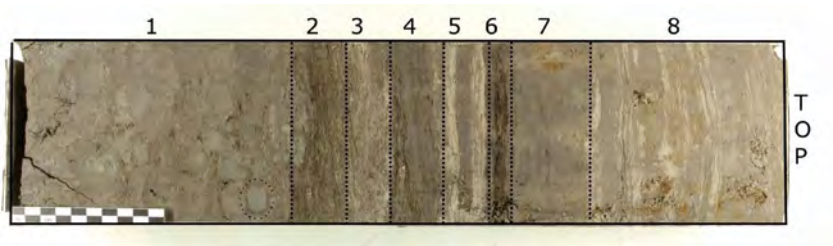
Figure B2.4 Metal sampling container with sample from Marssum. Compare with Table B2.2. The encircled clay lump in layer 1 is probably the result of erosion of 'clean' clay by running water

This hypothesis was, indeed, proven through the analysis of the plant macro-remains (Table B2.3). High numbers of foraminifera in layer 8 can be interpreted as a signal of flooding. They are probably primarily derived from the sand layers. Halophytes, such as *Suaeda maritima* and *Limonium vulgare*, are well presented

Layer	Depth	Description	Geogenesis
1	50-31	mixed clay	Low-energetic sedimentation
2	31-28	clay with thin organic layers	Little sedimentation, vegetation development
3	28-26	clay with multiple thin sand layers	High-energetic floods
4	26-23	clay with thin organic layers	Little sedimentation, vegetation development
5	23-20	thick sand and clay layers	High-energetic floods
6	20-19	Organic clay layer	Little sedimentation, vegetation development
7	18-14	mixed clay	Low-energetic sedimentation
8	14-0	clay with multiple thin sand layers	High-energetic floods

Table B2.2 Basic description of the layers in Figure B2.3

in this layer. Overall, the number of remains is low, especially considering the fact that layer 8 has by far the largest sample volume (Fig. 2.4). Layer 7 is quite similar to layer 8, but here even fewer remains were recovered.

Box 2 | **119**

The 'organic' layer, layer 6, did contain many more species. The low numbers of plant parts are related to the fact that the sample volume taken was lower than is usually the case for plant macro-remains (0.1 l). Nonetheless, the remains seem to represent a part of the landscape that contained high marsh vegetation but that does not seem to be as extremely dominated by ruderals as is usually the case in terp samples (Schepers *et al*. 2013a). Nevertheless, seeds from the low marsh species Salicornia europaea are also still present, as are *Sphagnum* leaves and *Erica tetralix*. Species of the low marsh occur frequently along ditches high up the marsh.

The 'bog' taxa *Sphagnum* and *Erica tetralix* will not have grown locally; they likely represent eroded, much older peat. This interpretation is strengthened by the analysis of a sample by the author from the present-day ditch in Fig. B2.1, which was also found to contain leaves of *Sphagnum*.

Taxon	Plant part	8	7	6	Salt marsh zone
Foraminifera	tests	++	+		Mud flats
Salicornia europeae	seed	2	1	5	Pioneer zone
Suaeda maritima	fruit	3	1	5	Pioneer zone
Aster tripolium	fruit	2			Low Marsh
Limonium vulgare	fruit	5		10	Low marsh
Plantago maritima	seed			1	Low marsh
Triglochin maritima	fruit			1	Low marsh / Brackish marsh
Oenanthe lachenalii	fruit			1	Brackish marsh
Chenopodium glaucum/rubrum	fruit	1		4	Brackish marsh
Juncus gerardi	seed	20			High marsh
Atriplex patula/prostrata	fruit	15	3	9	High marsh
Glaux maritima	seed			13	High marsh and drift lines
Cirsium arvense	fruit			2	Fresh anthropogenic grasslands
Bupleurum tenuissimum	fruit			1	High marsh
Tripleurospermum maritimum	fruit			3	High marsh and drift lines*
Taraxacum officinale	fruit			1	Fresh anthropogenic grasslands
Potamogeton pectinatus	fruit			1	Aquatic zone (brackish)

Chenopodium ficifolium	fruit	3	2	3	Drift lines*
cf. Urtica urens	fruit		1		Drift lines*
Erica tetralix	leaf			+	Heathland / peat*
Sphagnum	leaf			+	Heathland / peat*
cf. Luzula	fruit		1		-

Table B2.3 Plant macro-remains from case study 2. Ecological groups follow the TMAP typology of Esselink *et al.* (2009). Taxa not represented in that typology are assigned to one of these groups by me (indicated with *). Numbers represent absolute counts of retrieved plant parts. +=present, ++=numerous

DISCUSSION | Both case studies show that the analysis of plant macro-remains from a ditch outside the settlement allows for an easy and quick insight into the vegetation that existed in the vicinity of the sites but outside of the direct settlement noise. There are, however, a number of limitations.

First of all, the farther away from the settlement the sample is taken, the less likely it is that the sample can be dated through associated archaeological finds. Absolute dating methods work well, but, unfortunately, have no tradition for this type of deposit. Moreover, one should be very careful to select remains for dating that are believed to be more or less contemporaneous with the ditch, to prevent accidentally dating much older, reworked material. A good starting point for sample selection would be to consider the state of preservation (1). Remains that were deposited close to their origin are less likely to show traces of physical erosion than are remains that were redeposited from the erosion of older deposits. In addition, it is advisable to select remains of taxa that are presented in reasonable numbers, which makes local occurrence more likely (2). Plant traits, such as seed production, seed dispersal, and preservation potential, also need to be taken into account (3).

Another limitation is that the associated surface level is difficult to define. The arable weed assemblage identified as part of case study 1, for example, seems to point to a clay soil. It may therefore represent cultivation on the peat after some flooding events had already taken place. Peat soils are also known to have been 'enriched' with clay in areas where this was available

Box 2 | **121**

(e.g. Pals and Van Dierendonck 1988), but suggesting this for this area based on so little data would be mere speculation. The pollen signal seems to suggest that the associated surface level is gone. However, prehistoric fields are known to be hard to detect by means of pollen analysis (Bakels 2000).

The notion that palaeoecological analysis of ditch fill may be of significant value for a reconstruction of the surrounding environment is not new, nor is it restricted to coastal regions. However, ditch fill samples have traditionally been taken very close to excavated settlements (e.g. Beneš *et al*. 2002; Groenman-van Waateringe 1992; Manning *et al*. 1997), since these areas happen to be readily available for sampling during the course of the excavation.

It is therefore emphasized that, also in geological and palaeoecological research, sampling of ditch fill contexts away from the settlement deserves more attention. In Figure B2.5 this is visualized by means of a simplified section through a wetland landscape. Where ongoing chronological sequences are not available, a study of the fill of ditches farther away from the settlement may help to explain how far the impact of people on the landscape stretched.

Figure B2.5 Potential of ditch fill for reconstructing the surrounding vegetation. The vegetation of the crop fields and the grassland is carried into the settlement through harvesting and grazing or hay making. If no pure crop sample is retrieved in the settlement, the associated weeds are hard to distinguish from the settlement vegetation. The infill of the ditch directly adjacent to the settlement will contain a strong settlement signal. Where no long organic sequences have been preserved, information concerning the vegetation between the settlements can potentially be derived from ditches farther away from the settlements (for example, the central ditch shown here)

Dung Matters: An experimental study into the effectiveness of using dung from hay-fed livestock to reconstruct local vegetation

Schepers, M
Van Haaster, H

ABSTRACT | Following a renewed interest in manuring in archaeology, this paper explores the relationship between standing vegetation and dung from hay-fed cattle and sheep. In an experimental study, hay is retrieved from a known hay field, surrounded by a semi-open landscape of hedgerows, forests, and heather fields. The hay is fed to cattle and sheep, after which the dung is collected and from which the botanical remains are analyzed, according to archaeobotanical standards. The results from the macro-remains are compared to vegetation relevés from the hay field. The pollen analysis is compared to both the hay field and the surrounding vegetation. Results from the plant macro remains provide an excellent representation of the vegetation in the field itself on the presence/absence level. Pollen analysis reflects the regional vegetation very well and are comparable with 'surface samples'.

INTRODUCTION | In archaeobotany, and more particularly in the study of macroscopic plant remains (hereafter referred to generically as seeds in running text, unless the context necessitates a more specific term), the dung of herbivores has long since been regarded as a fruitful source of data for reconstructing past animal husbandry, be that grazing and fodder regimes or past vegetation (e.g. Brinkkemper 1993; Hall and Kenward 1998; Korber-Grohne 1967). The reason for this is obvious: dung from various animal species often holds a concentration of plant remains – in particular, endozoochorous diaspores (Cosyns and Hoffmann 2005; Janzen 1984; Stiles 1980; Stroh *et al.* 2012). Endozoochory is the dispersal of seeds through an animal's digestive system (as opposed to epizoochory, which is the dispersal of seeds by adhesion to an animal, for example by sticking to fur [Couvreur *et al.* 2005; Mouissie *et al.* 2005a; Sorensen 1986]). Studying dung will often result in a large number of seeds from a considerable number of taxa. Moreover, in wetland environments, dung is also an excellent sampling context for pollen analysis. Palynology may not only add information on the broader environment, it may also be a good alternative when too little dung is available to allow for macro-botanical analysis. This is especially relevant when multiple thin dung layers alternate with other sediments, allowing for a study of change over time (e.g. Woldring and Kleine 2008).

In this study, we attempt to shed some light on how variable the botanical composition of cattle and sheep dung is on both the qualitative and the quantitative levels. By this means, we intend to contribute to our understanding of the local and regional vegetation in a landscape where typical pollen contexts in the form of long peat sequences are lacking, but where dung is abundant – specifically, the Dutch terps area. Terps are man-made dwelling mounds erected in a salt marsh landscape (see Schepers *et al.* 2013).

In our experiment, hay from a modern-day grassland was cut and subsequently fed to both sheep and cattle to determine to what extent seeds and pollen in the dung of animals represent the vegetation in the hay meadows proper. In addition, we also investigated to what extent the data from the dung can be

used to reconstruct the vegetation pattern outside the meadows proper, namely, the surrounding, more regional vegetation. This signal is expected to be mainly represented by pollen, but also by wind-dispersed seeds that may be blown in from outside the grassland itself. When these seeds do not fall to the ground but instead stick to standing vegetation, they may also end up in hay and, ultimately, in animal dung (Cappers 2006).

A large number of studies deal with the relationship between vegetation and dung. These studies can be separated into two main categories. The first category encompasses ecological studies that focus on the relationship among grazing, endozoochorous dispersal, and the ability of diaspores to germinate in a different area than their source area (e.g. Bakker *et al*. 2008; Mouissie *et al*. 2005b; Wells and Lauenroth 2007). The second category encompasses archaeobotanical studies, where germination experiments are useless, since most seeds will have long ago lost their viability due to charring, waterlogging, or mineralization. Exceptions to this rule only occur under very specific and extremely rare conditions (e.g. Sallon *et al*. 2008; Yashina *et al*. 2012). Archaeobotanists are often not primarily interested in the germination potential of seeds that have gone through an animal's digestive system. As long as a seed can still be identified to a low taxonomic level, it has fulfilled its primary role in the possible reconstruction of vegetation. This means that fragments of seeds or other small plant parts still identifiable to an ecologically relevant taxonomic level (mostly to species), such as cereal rachis fragments, moss leaves, or fern apices, are equally important and are also taken into account when reconstructing vegetation.

Recently, a number of publications dealing with the taphonomy and interpretation of dung have appeared, the most prominent being the monograph *Manure Matters* (Jones 2012) and a special issue of *Environmental Archaeology,* edited by Marinova *et al*. (2013).

Shahack-Gross (2011, 215) summarizes the multiple ways in which plant material might end up in dung. Although her observations also pertain to palaeoenvironmental reconstruction, they primarily pertain to identifying past animal husbandry. She rightly emphasizes that fodder regimes and seasonality will

have a considerable effect on the composition of dung and, thus, on the vegetation to be constructed.

In the special issue of *Environmental Archaeology*, the experiment presented by Wallace and Charles (2013) and, to a lesser extent the study by Linseele *et al.* (2013) show considerable overlap with the issues addressed here. We refer to the study by Wallace and Charles (2013) for a concise recent overview of dung-related experiments in archaeobotany.

The experiments performed by Wallace and Charles (2013) show the discrepancy in composition between seeds that were fed to animals and those present in the dung these animals produce. Their study has the advantage that the authors knew exactly how many seeds of each taxon were consumed by the test animals in the experiment.

The focus in the current paper is on the relationship between dung and vegetation, as opposed to the exact number of seeds consumed (Fig. 4.1). In this experiment, we deal with dung from hay-fed animals. Dung from animals that were fed hay that was harvested from the same area will have a different composition than dung from animals that were allowed to graze in a landscape, because in the former scenario, the ability of animals to avoid less-preferred plant taxa or dried-out specimens is reduced considerably.

In wetland sites, deposits of exceptionally well-preserved dung are frequently encountered and selected for palaeobotanical analysis, often with the aim of reconstructing the local vegetation (e.g. Cappers 1995b, 2008; Kühn *et al.* 2013; Van Zeist 1989).

The interpretation of dung in archaeology is complicated by archaeologists' ability to recognize dung in the field (Körber-Grohne 1991, 11). Both Körber-Grohne (1967, 73) and Behre (1976, 25) conclude that what is generally labelled as 'dung' in excavation administration is likely to be typical byre mixture of dung, unconsumed hay, and straw. In terps, these dung labelled samples generally represent a mixture from a variety of vegetation types and appear to be surprisingly similar in botanical composition to the secondary fill of creeks and ditches on the presence/absence level (Schepers *et al.* 2013a). The present study was initiated to improve our interpretation of the frequent finds of dung layers in dwelling mounds in the northern Netherlands.
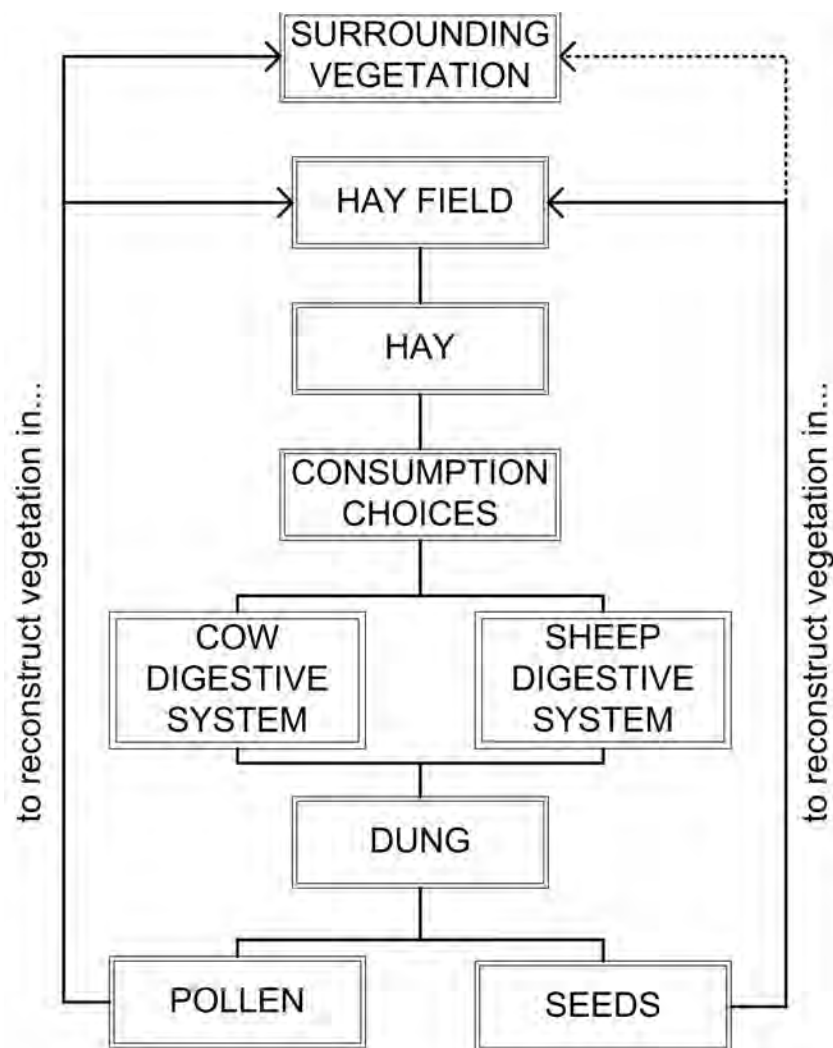
Figure 4.1 Flow chart for the subject of this paper. The term seeds here refers to all plant macro-remains

As Dieffenbacher-Krall (2007) points out, plant macro-remains may have the benefit of a deep taxonomic resolution, but because of their dispersal characteristics, they are less suited than pollen for estimating past abundances of identified taxa: "They are not systematically (linearly or unimodally) related to the variable (proportion of a species within a vegetational community) of interest" (pp. 2367–2368). Dieffenbacher-Krall's formula to translate seed

numbers into vegetation (about which he explicitly states that it does *not* hold) does not take into account that vegetation is generally not described in terms of number of individuals, but rather in terms of percentage of coverage by area. This is relevant because some taxa may cover a large surface while producing relatively few seeds, whereas other taxa, in contrast, may produce numerous seeds even though they cover only a relatively small area.

As stated above, numerous ecological studies deal with seed content in dung, but because ecologists studying present vegetation have no need to reconstruct vegetation, their focus is predominantly on seed dispersal. The non-zoological natural dispersal of seeds and the relationship to vegetation have been addressed in both palaeolimnological studies (Gaillard and Birks 2013) and in ecological studies dealing with water dispersal (Boedeltje *et al.* 2003; Wolters and Bakker 2002).

Far more studies have dealt with the relationship between pollen and vegetation than have dealt with seeds and vegetation (Berglund *et al.* 1986; Bunting 2003; Broström *et al.* 1998; Caseldine and Pardoe 1994; Court-Picon *et al.* 2005; Groenman-van Waateringe 1986; Overpeck *et al.* 1985). The long-distance dispersal of pollen allows for the interpretation of the vegetation composition at a greater distance from the actual sampling area – in most cases long organic sequences of peat or lake sediments. A key concept here is the 'relevant source area of pollen' (RSAP) (Sugita 1994), defined as the distance beyond which the correlation between pollen deposited at a site and the surrounding vegetation no longer improves (see also Broström 2002, 12). This means that reliable conclusions about the vegetation around a sampling site can only be drawn within the limits of the RSAP. Also, the size of the RSAP depends on the size of the basin in which the pollen is preserved (e.g. small hollows, ponds or lakes). The RSAP for surface samples (this study) is 400 m (radius around sampling site).

Pollen derived from dung found in archaeological contexts may be a valuable contribution to the interpretation of past landscapes if they are found to reflect vegetation in a comparable way to pollen from modern surface samples. In this study, we follow the figures defined by Groenman-van Waateringe (1986,

197) to evaluate the degree of openness of a landscape. From her experimental studies in the Netherlands, she concluded that arboreal pollen (AP) percentages of less than 25% in surface samples indicate an open landscape. Between 25% and 55% AP indicates open woodland, forest edge, or shrub, while over 55% AP indicates woodland. Pollen analysis on dung has frequently been used in archaeological research to reconstruct past vegetation (Akeret *et al*. 1998 and references therein; Carrión *et al*. 2000; Nieuwhof and Woldring 2008). Carrión *et al*. (2000), interestingly, present modern cow dung pollen samples to support their interpretation. In another study, dealing with grazing animals, Carrión suggests that samples from dung contain a combination of both local and regional flora, because each leaf eaten by a herbivore may contain pollen rain (Carrión 2002, 230). Although that study deals with dung from free-ranging animals, this pollen rain is also likely to be present on dung from hay-fed livestock.

In this study, we attempt to shed some light on how variable the botanical composition of cattle and sheep dung is on both the qualitative and the quantitative levels. The main research question is to what extent dung represents the local (seeds and pollen) and regional (pollen) vegetation. For plant macro-remains, following Dieffenbacher-Krall (2007), we expect the null-hypothesis of no relationship between sample composition and vegetation to hold on the quantitative level. We expect the alternative hypothesis of a clear relationship between sample composition and vegetation to be true on the qualitative level.

METHODS | Choice of hay field location | Because the dwelling mounds are situated in a salt marsh landscape, the initial intention was to obtain hay from a salt marsh area. Unfortunately, a wet summer in combination with the relatively modest size of the present marshes in comparison to the historic situation made this impossible. We considered inland grasslands used for grazing in commercial farming to be an unfit alternative because they are characterized by *Lolium perenne*-dominated, species-poor swards. Instead, we chose hay fields located in a heritage landscape national park encompassing a stream called the Drentsche Aa (Figs. 4.2 and 4.3).

Figure 4.2 The Drentsche Aa valley near Oudemolen, province of Drenthe, The Netherlands. The numbered dots indicate the locations of the vegetation relevés 1-12. The hay originated from both the field with the relevé plots and the two shaded fields. All three fields have a similar vegetation

The general area is dominated by the stream itself and consists of a mosaic of forest, riparian vegetation along the stream and hay fields – the type of vegetation that is suitable for answering our questions related to the diversity of plant taxa in dung as compared to that in the standing vegetation. The selection of the specific study area was based, first, on the taxonomic diversity of the meadows proper. The hay fields that we selected, mostly former cultivated areas that were abandoned several decades ago, have a great diversity of plant taxa, and this diversity makes them suitable for an experiment that includes seed analysis. The expected diversity of species in the hay makes this area a better source for comparison with the former salt marsh area than most present-day commercial grasslands. The second criterion was high variation in the surrounding vegetation; this makes a comparison with the pollen samples more complicated, but also more interesting. We can assess whether or not all vegetation units in the area are represented in accordance with their relative coverage in the pollen samples. The final selection

criterion was accessibility; the hay from this area could be relatively easily obtained.

Collecting hay (2011) | The hay fields near the village of Oudemolen are subject to normal seasonal variety in moisture, but, in contrast to the grasslands in the riparian zone, will not flood in wetter periods. The hay grasslands are mown in mid-summer, when many grassland species are in their fruiting stage. The plant material is left to dry on the field for several days. The drying process is stimulated by repetitive turning, thus resulting in both mixing of plant remains and declining diaspore density as diaspores fall onto the ground and become incorporated into the local seed bank, rather than being removed with the hay. Finally, the hay is packed in rolls approximately 1 m high and 1,5 m in diameter. In the summer of 2011, we obtained five of these rolls for the experiments.

Figure 4.3 Overview of the relevé hay field before mowing, looking northeast from relevé 1

Mapping the vegetation (2013) | We were unable to map the vegetation in 2011, since the hay had already been cut by the time the area was selected. We therefore mapped the vegetation two years later. In this experiment, the goal is to find out whether the reconstruction of vegetation from the dung is similar to the

vegetation that was present in the source area. It is therefore not essential that the relevés be taken on the actual vegetation that was to be fed to the animals. It is, nevertheless, acknowledged and emphasized that, because the vegetation that was mapped was not the actual vegetation collected, the present study does not meet the ideal situation of an unbroken *chaîne opératoire*.

The Drentsche Aa grasslands are extensive and diverse. This diversity is already apparent on a very local level. One extensive field was selected to create 12 relevés (plots), laid out in a systematic pattern. Each of the relevés measures 2x2 metres. Their position in the field was determined using a handheld GPS. In addition, a linear relevé measuring 2x10 metres was created along a shallow ditch that runs straight through the grassland.

The vegetation mapping was carried out in 2013. The relative coverage of the species were estimated using Braun-Blanquet scales for cover abundance, as available through the database system for vegetation data TURBOVEG (Hennekens and Schaminee 2010; see caption to Table 4.1). We scanned the grassland around the relevés to spot additional species that occurred rarely or only locally clustered in the field. In addition, we surveyed the vegetation pattern outside the grassland that lay within a 400-metre radius measured from the centre of the grassland. The size of this area corresponds to the area that is generally regarded as the RSAP for samples that are taken from soil surfaces (see above). All trees surrounding the meadows were inspected, and the relative abundance of the different taxa was estimated. The heath fields to the west and south of the grassland were not inspected in detail but can be described as typical heathlands, dominated by *Calluna vulgaris* and *Erica tetralix*.

The two-year gap between dung collection and vegetation survey | As stated above, the fact that the vegetation survey was carried out two years after the dung collection is a major flaw in the experimental set-up that we would have preferred to have avoided. How do we know that the vegetation composition of the grassland was similar (enough) to not render the whole study invalid? However tempting it might be to point to the good general match between the dung composition and the vegetation, this would

obviously constitute circular reasoning. A more convincing argument comes from the vegetation surveys in the area, which show very similar vegetation composition more than 20 years ago (Everts and De Vries 1991). Year-to-year variability in the vegetation is influenced by multiple factors, such as rainfall, temperature, and other weather conditions. Taking the total rainfall in June as a reference point, the values reported for the north of the province of Drenthe, where the sampled Drentsche Aa grasslands are situated, are very similar in 2011 (69.4 mm; KNMI 2011, 5) and 2013 (68.6 mm; KNMI 2013, 5). The average temperatures reported for June in both years show that it was slightly colder in 2011 (14.5 °C; KNMI 2011, 4) than in 2013 (15.6 °C, KNMI 2013, 4).The weather conditions not only influence the vegetation directly, but also determine the moment of hay-cutting. For these reasons (and additional factors that complicate these counts, as discussed below), the seed counts in particular should not be used for a direct comparison between dung samples and standing vegetation. But on a presence/absence level, we expect the differences between the two years to have been negligible.

Choice of animals as well as stabling and feeding regime | Most dung studied from the Dutch terps consists of cattle dung. Although many sheep bones have been identified, no sheep pellets have been recognized in this region. Given the excellent preservation of the organic material, this is noteworthy. Pellets have, for example, been recognized in sites with comparable preservation conditions along the Dutch west coast (Brinkkemper 1993, 84) and in numerous archaeological sites outside The Netherlands (Akeret *et al*. 1999 and references therein). The emphasis in this experiment therefore lies on cattle, but sheep were included as well, in order to establish whether or not their dung will show profound differences in botanical composition compared with cattle. A discussion of prehistoric animals' digestive systems and their effects on the preservation of plant materials in dung compared to modern animals' is beyond the scope of this paper. We used three cows and three sheep from the test facilities at Wageningen University, The Netherlands. The animals were fed

ad libitum, meaning plenty of hay was available for them at all times, theoretically allowing them to 'select' their food. To make sure no remains of previous feeding regimes could contaminate the dung samples, the animals underwent a three-week adaptation period (November 29–December 19) prior to the sampling period (December 20–23). We acknowledge that it is possible that, once the hay was placed in the feeding troughs at the Wageningen test centre, ambient local pollen, which would be very different in composition from the pollen in the study area, may have joined the study area pollen that was already present on the hay. But because the feeding experiments were carried out in December, that is, at a time when airborne pollen are only minimally present, little pollen contamination from pollen in the air at the feeding location is expected. As an extra safeguard, all animals were kept inside during the experiment, thus also making sure they had no access to food other than the hay intended for the experiment.

The cattle were kept separated from each other. They were tied to a bar running the length of the barn in order to allow for easy gathering of dung after defecation. Within several hours, the hay that had been presented to the cattle as fodder became sorted into coarse and finer material by the animals. It became moist with saliva. Hay was removed and replaced with fresh material when the animals appeared to have lost interest in the remaining hay.

The sheep were kept separated from each other during daytime only. A bucket of hay a day per sheep proved to be sufficient for the sheep to feed on. At night, the sheep were reunited and allowed to feed on the same kind of hay from a communal trough.

Sampling the dung | A total of 24 wet samples were secured – 12 for cattle and 12 for sheep. Throughout the day (08.45 AM–06.30 PM) all cattle dung was collected manually, directly following defecation. The night production was collected first thing in the morning. Both day and night production were weighed and subsequently mixed. Two 850 ml samples were taken from the mixture for each of the three animals. For each animal, one of these two samples was dried in a hot air drying chamber at 65 °C for 24 hours, thus producing a 'dung cake'. By weighing this dung

cake, we were able to determine the original relative proportion of moisture in the dung; this proportion was then used to calculate the absolute amount of dry matter in the wet sample.

Sampling of the sheep pellets was carried out during daytime only (9.00 AM–6.00 PM). Droppings were gathered continuously, to prevent the sheep from trampling them or mixing them up with the hay. The whole day's worth of production per animal was taken as a sample.

Processing the dung samples | After being soaked in hot water for several days, both the cow and the sheep dung samples readily dissolved. For the pollen analysis, samples were taken from four of the wet cattle samples and from two of the sheep samples. The samples were prepared following Faegri and Iversen (1989). For the seed analysis, all wet samples were sieved separately over a stack of sieves with mesh aperture sizes of 2.0, 1.0, and 0.5 mm. No mechanical force or manual pressure was applied during sieving.

All twelve cattle samples were sorted completely. The total seed count was corrected to an equal amount of dry matter, normed to the sample with the highest absolute amount of dry matter as a starting point. This correction was performed to allow for comparison of plant remains based on the density of seeds in the plant material only, irrespective off the moisture component (i.e. water).

Six of the sheep samples (those collected during the first two days) were analyzed, but because of the low density and variety of seeds present, only about half of the 0.5 mm sieve residue was sorted. The relative proportion of the amount of residue in the samples was measured in ml. By measuring the unsorted residue of the 0.5 mm sieve as well, the seed counts in the residue could be corrected to the total sample.

RESULTS | **Vegetation relevés** | The results of the mapping of the standing vegetation in the relevé field are presented in Table 4.1. A number of species dominated the vegetation (Fig. 4.4). These were the grasses *Holcus lanatus* and *Anthoxanthum odoratum* and the common grassland herbs *Plantago lanceolata*, *Leontodon autumnalis*, and *Rumex acetosa*. Plants of wetter stands were represented by

Galium palustre, Phragmites australis, and *Ranunculus flammula,* the latter two being concentrated along the shallow ditch (relevé 13).

Figure 4.4 Variety in species composition in the studied hay field. Clockwise from top left: relevé 3, relevé 5, relevé 11, and relevé 12

In relevés 10 and 11, seedlings of *Betula* and *Quercus* were present, emphasizing the possible vegetation development in the area if mowing practices were to be abandoned (Fig. 4.5). Relevés 10 and 11 are located along the edge of the field, and included such species as *Anthriscus sylvestris*, *Urtica dioica*, and *Dactylis glomerata*, pointing to more nitrogen-rich soils. A small concentration of *Juncus articulatus* was present in a less well-drained area not included in the relevés. All relevés except for number 13 can be identified as grasslands within the *Molinio-Arrhenatheretea*, in this case represented by semi-natural, wet to moist hay field (syntaxonomy follows Schaminée *et al.* 1996). These grasslands are common in the Drentsche Aa stream valley (Everts and De Vries 1991).

Vegetation pattern surrounding the sampled grassland established through the RSAP survey | The landscape within in a 400 m radius of the sampled grassland can be characterized in general as

open to semi-open. To the west, north, and south, the landscape consists mainly of grasslands dissected by hedgerows with trees and shrubs or grassy heathland vegetation. The sampled grassland itself is surrounded by a 5–10 metre wide hedgerow, which as far as the trees and shrubs are concerned consist mainly of *Betula, Quercus, Betula,* and *Prunus serotina/padus. Rubus fruticosus, Salix* spp, *Lonicera peryclymenum, Sorbus aucuparia, Corylus avellana,* and *Sambucus nigra* are also present. To the east of the sampled grassland lies a dense forest dominated by *Quercus* and *Fagus* (see Figs. 4.2 and 4.3). *Alnus* is present on wet locations along the Drentsche Aa stream.

Relevé number	1	2	3	4	5	6	7	8	9	10	11	12	13
Anthoxanthum odoratum	1	1	1	1	1	1	1	1	1	1	1	r	+
Holcus lanatus	2a	1	2a	1	+	r	2a	1	2b	+	1	1	+
Plantago lanceolata	2a	3	2b	3	+	4	2b	3	2b	2a	4	3	
Leontodon autumnalis	2a	+	2a	+	r	+	2a		1	r	+	2a	
Rumex acetosa	+	2a	r	r	r		+		+	r	2a	r	
Rhinanthus angustifolius	2a			+	2a	1	+		+	+		2a	+
Cirsium palustre	r	r		r				r		1	r	r	
Ranunculus acris	2b	3			+			+	2a	r	2a		
Cerastium fontanum	r	2a	+				+				r	+	
Cynosurus cristatus	1	1		r	r		+						r
Poa pratenis	1	1			1		1			1	1		
Ranunculus repens			2a	3	+	2b		2b					
Dactylorhiza majalis subsp. majalis	+	+	r				r						
Juncus effusus		r			2a			2a		2b			4
Cardamine pratensis									r		r	r	
Cirsium		r				r	+						
Galium palustre			r						r				2b
Hypochaeris radicata										2b	r	2a	
Trifolium pratense		+		+								2a	
Trifolium repens	2b			+					r				
Agrostis capillaris										2b		r	
Deschampsia cespitosa	+	2a											
Festuca pratensis	1	+											
Ranunculus							2b						2a

Bellis perennis		+		
Betula				r
Carex ovalis			r	
Luzula campestris		+		
Phragmites australis				+
Quercus			r	
Quercus robur				r
Ranunculus flammula				2a
Rubus fruticosus			r	

Table 4.1 Composition of 13 relevés in the Drentsche Aa grasslands. See Fig. 4.2 for the location of the relevés. r=very few, +=few, 1=numerous, 2a=5–12.5 % coverage, 2b=12.525 % coverage, 3=25–50 % coverage, 4=50–75 % coverage. Species are ordered according to the number of relevés in which they occur and within that alphabetically

Figure 4.5 Seedlings of birch (*Betula,* left) and oak (*Quercus*, right) in relevé 11

Cattle dung | The relative proportion of dry matter in the cattle dung samples is presented in Fig. 4.6. The dung cakes produced are stored. It proved, in general, rather easy to produce solid dung cakes fit to be stored from dung alone – that is, without using any admixture such as threshing remains (Fig. 4.7). A total of 3757 seeds were collected and identified from the wet samples.

A large number of moss fragments (not counted) were also recovered from the dung. By correcting all values to the highest dry matter content, which allows for comparison among samples, the total number of seeds is 5418 (Table 4.2). The density of seeds per 100 grams of dry matter (average=146) is also presented in Table 4.2. The samples are coded according to the cow number and the sampling day. For example, sample C1.3 is the sample taken from cow 1 on the third sampling day.
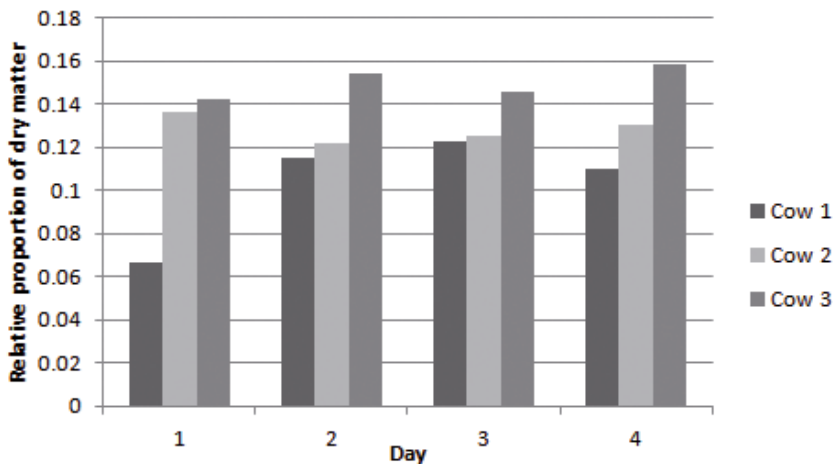
Figure 4.6 Relative proportion of dry matter for the cattle samples. The seed counts for the cattle samples were corrected to the highest absolute amount of dry matter based on these proportions

Since *Poa* was extremely dominant in all samples, its fruits and florets are not included in the seed density calculation. Including them would cause the density differences among the samples to be primarily indicative of the fluctuations of a single taxon. Although substantial variation in seed density exists among samples C1.2 to C3.4 (between 69 and 163 seeds per 100 grams), the seed density of sample C1.1 stands out. As indicated by the dry matter content (Fig. 4.6), this animal clearly suffered from diarrhoea that day–which was, in fact, observed during sampling. Although the absolute amount of dry matter in the sample was lower, the diarrhoea appears to have had a positive effect on the seed survival rate, presumably due to the faster rate of passage through the digestive tract.

Figure 4.7 'Dung cake' created from one of the cattle dung samples, ca. 40 cm in length

For a number of taxa, different plant parts were counted separately if encountered as such; seeds and fruits were not counted if they were part of a higher morphological unit. For example, although a compete spikelet of *Anthoxanthum odoratum* undoubtedly contains its caryopsis, the latter is not counted as a fruit also. A number of taxa are present in practically all samples. The ratios between these ubiquitous taxa vary considerably. The fruits of *Anthoxanthum odoratum*, for example, were found in low numbers in samples C2.2 and C3.1. Sample C3.1, however, does contain the highest number of *Carex ovalis* fruits utricles. A remarkable high number of *Juncus effusus* fruits (seeds were not counted because of their very small size) was recovered from sample C2.1. Other noteworthy species are the domesticate *Hordeum vulgare* in samples C1.1 and C1.2, as well as *Atriplex* and *Chenopodium album*, being possible associated arable weeds.

Sheep pellets | A total of 558 seeds were counted from the sheep pellets; this number was converted to a total of 806 by taking into account the unsorted portion of the 0.5 mm fraction (Table 4.3). The sample codes work the same way as those for cows: S1.1.

is the sample taken from sheep 1 at day 1. In terms of method, it should be mentioned here that the seed analysis from the sheep samples proved much more time-consuming than that from the cow samples. Even after sieving, much of the plant material was considerably more entangled, which necessitated manual separation with tweezers to search for seeds.

However, because manual separation was carried out consistently and thoroughly, this initial entangling is not likely to have affected the results.

A striking difference from the cow samples is the much lower number of taxa. We had expected *Juncus effusus* to be present in low numbers only, because during the feeding regime we observed that the relative proportion of *J. effusus* stems in the hay bucket increased during the day, suggesting avoidance of the stems by the sheep. The cow's physique did not allow for this subtleness. Oddly enough, this observation could not be confirmed by the seed analysis, suggesting that the sheep avoided the *J. effusus* stems more than the infructescences. S2.2. stands out for having a higher number of taxa, although all but *Rumex acetosella* are represented by a single seed only.

Pollen analysis | The full results of the pollen analyses are presented in appendix A. The pollen samples (from cattle and sheep) displayed more taxonomic variation, resulting from the ability of pollen to be dispersed over greater distances. The Arboreal Pollen (AP) percentages in the dung samples varied from 5.7% to 20.3% (Fig. 4.8).

The trees that were best represented in the dung samples are *Quercus*, *Betula*, *Corylus*, and *Alnus*, which are wind-pollinated taxa. *Quercus*, *Betula*, and *Corylus* are the main components of the surrounding hedgerow, and *Alnus* is the dominant tree along the Drentsche Aa stream. Other trees and shrubs that are present in the surrounding hedgerow (*Sorbus*, *Lonicera*, *Rubus*, *Sambucus*, and *Salix*) are insect-pollinated taxa. These taxa produce lower quantities of pollen than do wind-pollinated taxa and are therefore less well represented in the dung samples. Pollen from *Fagus*, a wind-pollinated tree that is very well represented in the forest to the east of the sampled grassland, is hardly present in

Taxon	Plant part	C1.1	C1.2	C1.2	
Anthoxanthum odoratum	fruit	22.7	20.6	28.8	
Anthoxanthum odoratum	floret	25.2	24.7	22.3	
Carex ovalis	fruit and utricle	181.4	38.4	5.2	
Juncus effusus	fruit	315	63	23.6	
Musci	vegetative part	xxx	xx	x	
Plantago lanceolata	fruit	12.6	4.1	13.1	
Plantago lanceolata	seed	45.4	34.3	39.3	
Poa	fruit	471.2	164.4	163.8	
Poa	floret	121	82.2	53.7	
Ranunculus acris / repens	fruit	32.8	7	9.2	
Galium palustre	seed	17.6	1.4	6.6	
Alopecurus	floret			1.3	
Festuca	floret	5		1.3	
Rhinanthus	seed		4.1	1.3	
Betula	fruit		1.4		
Cynosurus cristatus	infructescence	2.5	1.4	3.9	
Leontodon utumnalis	fruit			1.3	
Cirsium	fruit	2.5			
Rhinanthus	fruit			1.3	
Rumex acetosa	fruit		2.7	2.6	
Cerastium fontanum	seed				
Cynosurus cristatus	fruit		1.4		
Holcus lanatus	floret			2.6	
Hordeum vulgare	rachis node	15.1	1.4		
Atriplex	fruit			1.3	
Chenopodium album	fruit			1.3	
Eleocharis palustris	fruit	5			
Prunella vulgaris	fruit				
density (per 100 g, excluding Poa)		498	150	121	

Table 4.2 Scaled number of diaspores per sample in dung samples from three cows (C1, C2, and C3), sorted on ubiquity. The decimals are the result of correction of all samples to an equal amount of dry matter, normed to sample C3.2. The branches of *Musci* have been quantified into three categories: x=some; xx=many; xxx=very many

the dung samples, probably as a result of the fact that the prevailing wind originates from the southwest. The regional vegetation

C1.4	C2.1	C2.2	C2.3	C2.4	C3.1	C3.2	C3.3	C3.4
35.3	7.9	3.8	43.2	38	2.3	14	22.8	18
25	6.6	14.1	17.6	43.8	8.2	8	27.8	29.2
4.4	58.1	23	16.2	4.4	59.6	30	15.2	7.9
48.5	109.6	33.3	31.1	8.8	37.4	50	21.5	4.5
xx	x	xx	xx	xx	xx	xx	x	x
38.2	5.3	3.8	10.8	14.6	3.5	4	7.6	2.2
26.5	9.2	6.4	19.6	24.8	10.5	10	19	15.7
172	184.8	102.4	222.8	121.2	142.6	155	131.6	164
98.5	62	43.5	85.1	40.9	98.2	44	59.5	49.4
15.6	4.8	1.3	12.3	5.8	16.7	8	11.4	9.5
10.3	11.9	5.1		2.9	1.2	1	2.5	2.2
7.4	4	1.3		1.5	1.2			
	2.6		1.4	2.9	1.2			
4.4			1.4	1.5				2.2
	1.3	1.3				1		1.1
1.5						2		
		0.6		1.5			1.3	1.1
1.5				1.5	1.2			
1.5			1.4					1.1
2.9							1.3	
				1.5		3		
							2.5	
						2		
				1.5				
163	161	69	113	113	104	97	97	69

as a whole as reconstructed from the pollen diagrams therefore appears somewhat more open than the actual vegetation. All samples are dominated by grassland taxa, especially Poaceae, *Plantago lanceolata*-type, Asteraceae Liguliflorae (which includes *Leontodon autumnalis*), and *Ranunculus acris*-type. Other grassland taxa are present in lower proportions.

Taxon	Plant part	S1.1	S1.2	S2.1	S2.2	S3.1	S3.2
Poa	fruit	68.2	43.3	162.6	57.6	55.5	30.8
Poa	floret	72.1	15.2	38.4	12.0	21.7	10.6
Anthoxanthum odoratum	fruit	6.4	7.7	2.4	11.4	4.9	16.9
Anthoxanthum odoratum	floret	5.4	8.0	4.0	4.0	1.0	1.5
Juncus effusus	fruit	13.0	3.0	15.4	5.8	8.0	
Carex ovalis	fruit and utricle	13.3	1.7	16.3		9.0	1.8
Ranunculus acris/repens	fruit		2.0	1.0	1.5	0.7	0.7
Plantago lanceolata	fruit	4.0	5.0	2.0	4.0	2.0	
Musci	vegetative part	x	x		x	xx	xx
Festuca	floret		1.0	2.0	1.0	2.0	1.0
Plantago lanceolata	seed	7.2		1.0	2.0	3.0	
Galium palustre	fruit	1.8		2.0			
Rhinanthus	seed			1.0			1.0
Holcus lanatus	floret				1.0		1.8
Alopecurus	floret				1.0		
Cynosurus christatus	infructescence				1.0		
Cynosurus christatus	fruit				1.0		
Rumex acetosa	fruit				2.8		

Table 4.3 Taxonomic composition of the sheep pellets, ordered by ubiquity and within that alphabetically. The branches of Musci have been quantified into two categories: x=some; xx=many

Within the grassland taxa, there is a noteworthy variation between the *Plantago lanceolata* and Poaceae values in the cow samples. The *Plantago lanceolata* pollen values in the day 4 samples are remarkably lower than those in the day 1 samples. The pollen from *Calluna vulgaris* (3.9–9.8 %) comes from patches of grassy heathland located in the northern, western, and southern areas of the sampled grassland.

DISCUSSION | Comparison between the dung samples and the vegetation | This study explores the effectiveness of using dung from hay-fed livestock in order to reconstruct the surrounding standing vegetation, as opposed to using archaeological dung to study prehistoric farming methods (Akeret *et al.* 1999; Karg 1998). With this objective in mind, three main factors are relevant for fully understanding vegetation reconstruction: vegetation, hay, and dung. Hay as such has not been the subject of the present
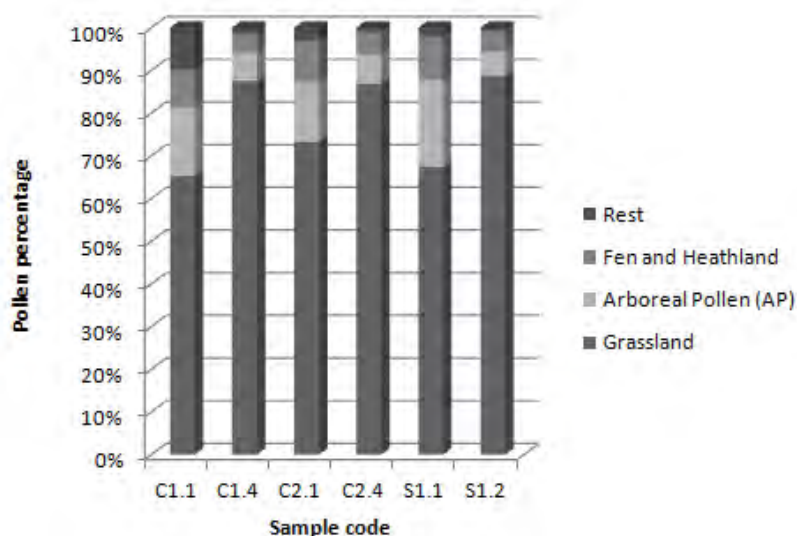
Figure 4.8 Proportion of grassland, fen and heathland, and arboreal pollen in the pollen samples

study, primarily because it is rarely encountered in archaeobotany. Moreover, it would require a considerable amount of extra lab work and substantial extra discussion, which is beyond the scope of this paper. We recommend it be the topic of future studies.
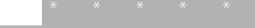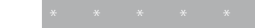
The dung samples of both sheep and cattle correspond well with the vegetation as recorded in the field (Table 4.4). In Table 4.4, we chose to merge *Ranunculus acris/repens* for the vegetation category, although they were mostly identified to the species level in the vegetation. We assumed that *Rhinanthus* in the seed samples most likely represents *Rhinanthus angustifolius* and that *Cirsium* represents *Cirsium palustre*, in accordance with the sampled vegetation. This results in a total of 35 taxa.

Twelve of these taxa were found in the vegetation, the cow dung samples, and the sheep pellets. Of these, *Anthoxanthum odoratum*, *Plantago lanceolata*, and *Ranunculus acris/repens* are found in almost all samples. These three taxa possess relatively large, easily identifiable seeds – as do most of the taxa that were so ubiquitously present. *Galium palustre*, less frequent in the vegetation than in the cow dung samples, stands out in terms of its ecology and growth form. Its small fruits do not occur in spikes, like

Taxon	Vegetation
Anthoxanthum odoratum	* * * * * * * * * * * *
Plantago lanceolata	* * * * * * * * * * * *
Ranunculus acris/repens	* * * * * * * * * * * *
Poa	* * * * * * * *
Juncus effusus	* * * *
Carex ovalis	*
Holcus lanatus	* * * * * * * * * *
Rhinanthus angustifolius	* * * * * * *
Galium palustre	* * *
Rumex acetosella	* * * * * *
Cynosurus cristatus	* * * * * *
Festuca pratensis	* *
Leontodon autumnalis	* * * * * * * * *
Cirsium palustre	* * * * * * * *
Cerastium fontanum	* * * * * *
Betula	*
Alopecurus	
Dactylorhiza maj. subsp. maj.	* * * *
Cardamine pratensis	* * *
Hypochaeris radicata	* * *
Trifolium pratense	* *
Trifolium repens	* * *
Agrostis capillaris	* *
Deschampsia cespitosa	* *
Quercus	* *
Bellis perennis	*
Luzula campestris	*
Phragmites australis	*
Ranunculus flammula	*
Rubus fruticosus	*
Hordeum vulgare	
Eleocharis palustris	
Atriplex	
Chenopodium album	
Prunella vulgaris	

Table 4.4 Comparison of standing vegetation (v), cattle dung samples (c), and sheep dung samples (s) on a presence/absence level. The taxa are ordered in groups, indicated with a dashed line (except for group 1). Group 1=v+c+s; group 2=v+c; group 3=c+s; group 4=v; group 5=c

they do in most grasses in this experiment (see also Fig. 4.10) and in *Plantago lanceolata*. Nor are its multiple fruits implanted

	Cow dung	Sheep dung	cnt.
			31
			29
			29
			24
			21
			18
			17
			17
			16
			15
			13
			13
			16
			14
			8
			6
			7
			4
			3
			3
			3
			3
			2
			2
			2
			1
			1
			1
			1
			1
			2
			1
			1
			1
			1

into the receptacle of one flower, like they are in *Ranunculus* species (Cappers and Bekker 2013). Whereas Poaceae, *P. lanceolata*, and *Ranunculus* would potentially result in the consumption of about 30 seeds in a single bite, for *G. palustre* this would be only 2 seeds (numbers from LEDA, Kleyer *et al.* 2008). This difference

in growth form is probably at least as significant for understanding the seed composition in dung as is seed production.

Seed counts are highly problematic for additional reasons. Using seed production to address the ratio between taxa in actual vegetation is problematic because of the high interspecific variability among samples. Moreover, seed production is already highly variable at the intraspecific level, influenced by such factors as differences in reproductive allocation and effort (Bazzaz *et al.* 1992), pollination failure (Fenner 1985), and pre-dispersal seed predation (Crawley 1992).

Alopecurus is occasionally found in the cattle and sheep dung samples, but has not been witnessed in the standing vegetation. *Carex ovalis* is found in the dung samples in both high frequency and high numbers. This species is known to occur in grasslands like the ones that were part of this study but to disappear through ongoing oligotrophication of hay fields (Weeda *et al.* 2003, 334–335). In combination with the incidental finds of ruderal plants and even some rachis fragments of barley (*Hordeum vulgare*), these finds indicate either that the grassland was more nutrient-rich when the hay was cut or, more likely, that the hay contained at least some material from richer grasslands.

The presence of *Betula* fruits in the cattle dung samples indicates that such diaspores not only end up in the soil, where they can eventually germinate (Fig. 4.5), but also easily become attached to the standing vegetation. In this way, they become part of the diaspore composition of hay and thus part of the dung. They do not relate to the specimens in the field (such as shown in Fig. 4.5), as these seedlings would not be fruiting yet. The morphology of *Betula* fruits allows them to be transported over great distances. In palaeolimnological studies, they are a prime example of one of the few taxa usually found near the centre of deep lakes (Birks 1973, 180). In other words, the adhesion of seeds to upright plants should also be considered for species with diaspores that are not equipped for adhesion – for example, needles or the bristle-shaped pappi in the Asteraceae family.

As shown in Tables 4.1 and 4.4, most of the taxa that were identified in the relevés but not retrieved from the dung were present in low abundance and frequency in the standing

vegetation. Other factors influencing this 'lack of visibility' are seed size – for example, in *Dactylorhiza majalis* subsp. *majalis* (because the microscopic seeds of most orchids pass through the smallest sieves used in this study) – and lack of seed production due to the phenophase of the plant (*Quercus*; see Fig. 4.5). There are also taxa, such as *Trifolium,* whose absence in the samples is more surprising. In our experience, this member of the Pea family is highly appreciated by grazing animals, and its diaspores (seed embedded by fruit and calyx) are generally easy to identify.
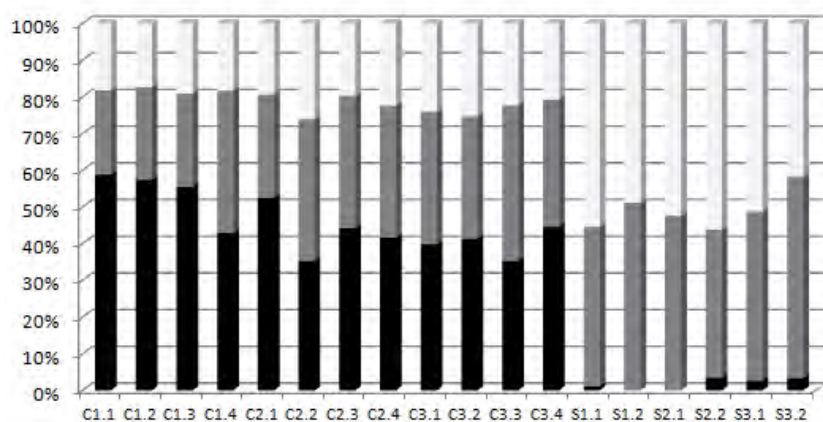
Figure 4.9 Relative proportion of total amount of organic residue by sieve aperture size. C=cattle, S=sheep. Black=2.0 mm sieve; grey=1.0 mm sieve; white=0.5 mm sieve

A prime difference between the cattle dung and the sheep dung is the lower presence of larger seeds in the sheep pellets. This difference is in line with the findings by Wallace and Charles (2013), who observed that relatively few seeds exceeding 2.0 mm were recovered from the sheep dung intact. Note that hardly any residue remained on the 2.0 mm sieve (Fig. 4.9) and that relatively large diaspores, such as the seeds produced by *Plantago lanceolata* or the fruits of *Ranunculus acris/repens,* were indeed found in lower numbers in the sheep pellets than in the cow dung (Tables 4.2 and 4.3). Due to the fact that fragments of seeds can also mostly be identified to species level, these do not cause differences between the combined sheep samples and the combined cattle samples on the presence/absence level (Table 4.4).

The main differences between the cattle and sheep samples are in taxa that have been found in only low numbers and frequencies in the cattle dung as well, such as *Betula*, *Cerastium fontanum*, and *Chenopodium album*.

The variety of dominant taxa within the combined sheep samples and the combined cattle samples, respectively, emphasizes a remarkable effect. Despite the fact that the hay had been cut, turned over several times in the field, wrapped, consumed by the animals, and sieved over a stack of sieves, the plant dispersal units still tended to retain a form of clustering. By 'a form of clustering' we mean that despite all the taphonomic potential mixing processes mentioned above, the composition of the dung had not yet reached a point where the ratios among the dominant taxa were more or less the same.

The results from the pollen samples are very consistent with those from the seed samples. 'Type' identifications for *Plantago lanceolata, Ranunculus acris*, and *Rumex acetosa* probably pertain to these respective species. The high numbers of Poaceae pollen correspond well with *Anthoxanthum odoratum, Poa, Cynosurus cristatus*, and *Holcus lanatus* in the standing vegetation. An increase in the *Plantago lanceolata* values for samples C1.4 and C2.4 can also be observed in the seed samples. The results fit very well with the vegetation pattern beyond the sampled grassland as established through the RSAP survey, which was characterized as open to semi-open. The variation in arboreal pollen values may be explained by differences in the origin of the hay, with the higher arboreal pollen percentages coming from the east (forest edge) side of the grassland. It is an important finding that the pollen samples from dung in this experiment seem to correspond quite well with surface samples from comparable landscapes (see Groenman-van Waateringe 1986).

Implications for archaeological vegetation reconstruction | The comparison between the standing vegetation and the dung samples, in terms of both seeds and pollen, as presented above, specifically deals with the degree of similarity between the samples. This experiment was set up in order to see to what extent these samples would lead to a correct reconstruction of the vegetation.

Figure 4.10 *Cynosurus cristatus* in different phenophases in relevé 1. From left to right: flowering, withered, and fruiting

There are several ways to approach vegetation reconstruction, ranging from loose descriptions to a comparison with detailed descriptions of present-day plant communities (Schepers *et al.* 2013). Loose descriptions are mostly based on the botanical knowledge of the archaeobotanical analyst, which would undoubtedly lead to the identification of a grassland here. If we take a standard

system for ecological groups for the Netherlands as a reference (Arnolds and Van der Maarel 1979), both the vegetation relevés and the dung samples are dominated by species from eutrophic soils (category 2a) and manured grasslands (5a). The tree signal is only poorly represented in the seed samples, by the presence of *Betula* fruits, whereas the heathlands are absent. It is only the combination of the pollen and the seed analysis that leads to a rather complete reconstruction of both local (the meadow) and regional vegetation.

Very detailed vegetation reconstruction of the hay land is more easily executed based on the cow dung than on the sheep pellets, especially when trying to match the results of the analysis to present-day plant communities. This is because in plant communities, the combination of taxa is of high relevance, whereas in standard ecological grouping, the individual characteristics of a taxon are leading. A higher number of species will therefore lead to a more reliable reconstruction.

GENERAL CONCLUSIONS | In general, this study has shown that on the presence/absence level, dung produced by hay-fed animals is very well suited for a reconstruction of local vegetation through the analysis of seeds and pollen. Seed counts however, should be used with caution. As this study shows, they can be highly variable and are not necessarily directly related to the ratios among taxa in the standing vegetation. The seed counts should therefore not be used to calculate the absolute ratios among taxa in vegetation. A relevant interpretation based on the seed counts that does seem valid, however, is that the source vegetation must have been patchy, as was found to be the case in the vegetation relevés. The ratio among seeds from dung samples is likely to be the result of a mixture of patches with different ratios for taxa that are present in both.

That pollen and seeds are produced and dispersed in different phenophases of a plant considerably influences the botanical content of the dung. With specific regard to hay, late seed setters, in particular, are less likely to be in seed at the time of year when hay is typically harvested (although we acknowledge that this timing is also determined by the decisions of farmers).

To a lesser extent, this also goes for early seed setters. Moreover, the different phenophases do not happen simultaneously for all individuals (Fig. 4.10).

Most dung-vegetation experiments in ecology focus on free-ranging animals and on seed germination. As a vehicle for plant dispersal, cattle dung will definitely be better suited than sheep dung, at least as far as relatively big seeds are concerned. Moreover, at least in cattle, diarrhoea tends to have a positive effect on the seed survival rate. The archaeological relevance of this observation is limited to the fact that it emphasizes once more that there are many uncontrollable and probably unrecognizable factors that determine the composition of dung, especially in relation to seed counts.

A future experiment would require better control of the exact source of all hay and, ideally, a comparison with dung from livestock grazing on standing vegetation in the same location. Despite the limitations of the current study, we believe that analyzing the botanical content of dung from animals fed with hay provides a good picture of the source grassland.

APPENDIX TO CHAPTER 4

Sample name	C1.1	C1.1	C1.4	C1.4	
Number (N) and Percentage (%)	N	%	N	%	
Totals					
Arboreal Pollen (AP)	80	17,4	30	6,7	
Non Arboreal Pollen (NAP	379	82,6	421	93,3	
Total Pollen Count (AP+NAP)	459	100,0	451	100,0	
Pollen Concentration N/ml	45090		35874		
Trees and shrubs					
Betula	16	3,5	8	1,8	
Alnus	25	5,4	8	1,8	
Carpinus betulus	1	0,2	.	0,0	
Corylus	9	2,0	7	1,6	
Fagus	1	0,2	.	0,0	
Fraxinus excelsior-type	1	0,2	.	0,0	
Juniperus communis-type	2	0,4	.	0,0	
Pinus	9	2,0	.	0,0	
Quercus	15	3,3	4	0,9	
Salix	.	0,0	.	0,0	
Sorbus-group	.	0,0	1	0,2	
Tilia	1	0,2	2	0,4	
Ulmus	.	0,0	.	0,0	
Cultivated plants					
Hordeum/Triticum-type	1	0,2	.	0,0	
Secale	1	0,2	.	0,0	
Grassland					
Asteraceae liguliflorae	12	2,6	67	14,9	
Filipendula	.	0,0	.	0,0	
Plantago	1	0,2	.	0,0	
Plantago lanceolata-type	60	13,1	150	33,3	

	C2.1	C2.1	C2.4	C2.4	S1.1	S1.1	S1.2	S1.2
	N	%	N	%	N	%	N	%
	66	13,8	45	6,9	59	20,3	15	5,7
	414	86,3	603	93,1	232	79,7	250	94,3
	480	100,0	648	100,0	291	100,0	265	100,0
	26073		45727		65616		78987	
	16	3,3	15	2,3	21	7,2	5	1,9
	15	3,1	13	2,0	24	8,2	5	1,9
	.	0,0	1	0,2	.	0,0	.	0,0
	10	2,1	4	0,6	3	1,0	1	0,4
	.	0,0	1	0,2	2	0,7	.	0,0
	1	0,2	1	0,2	.	0,0	.	0,0
	.	0,0	.	0,0	.	0,0	.	0,0
	5	1,0	4	0,6	3	1,0	1	0,4
	16	3,3	4	0,6	5	1,7	3	1,1
	1	0,2	.	0,0	.	0,0	.	0,0
	.	0,0	2	0,3	.	0,0	.	0,0
	1	0,2	.	0,0	1	0,3	.	0,0
	1	0,2	.	0,0	.	0,0	.	0,0
	2	0,4	1	0,2	.	0,0	1	0,4
	.	0,0	1	0,2	.	0,0	.	0,0
	14	2,9	105	16,2	5	1,7	90	34,0
	.	0,0	.	0,0	1	0,3	1	0,4
	.	0,0	3	0,5	.	0,0	.	0,0
	98	20,4	244	37,7	56	19,2	82	30,9

Poaceae	230	50,1	165	36,6
Poaceae >40 µm	2	0,4	.	0,0
Ranunculus acris-type	16	3,5	8	1,8
Rumex acetosa-type	1	0,2	4	0,9
Rumex acetosella	1	0,2	1	0,2
Succisa-type	.	0,0	.	0,0
Ruderals and weeds				
Artemisia	3	0,7	.	0,0
Chenopodiaceae p.p.	.	0,0	.	0,0
Urtica dioica-type	2	0,4	5	1,1
Fen and heathland				
Calluna vulgaris	37	8,1	18	4,0
Erica tetralix-type	.	0,0	1	0,2
Ericaceae	3	0,7	1	0,2
Myrica gale	.	0,0	.	0,0
Sphagnum	3	0,7	.	0,0
Dryopteris-type		0,0		0,0
Nonspecific ecology				
Cyperaceae	.	0,0	.	0,0
Apiaceae	.	0,0	.	0,0
Asteraceae tubuliflorae	.	0,0	.	0,0
Brassicaceae	3	0,7	.	0,0
Carduus/Cirsium	.	0,0	.	0,0
Fabaceae p.p.	1	0,2	.	0,0
Rubiaceae	2	0,4	1	0,2
Not identifiable	6	1,3	5	1,1

A review of prehistoric and early historic mainland salt marsh vegetation in the northern-Netherlands based on the analysis of plant macrofossils

Schepers, M
Cappers, R.T.J.
Bekker, R.M.

ABSTRACT | The article presents an overview of archaeobotanical research on artificial dwelling mounds, so-called 'terps', in the northern-Netherlands. A total of forty studies carried out over the past forty years is evaluated. The vegetation diversity in the area as well as the differences with the present marsh are studied. Seriation, Principal Component Analysis and Sørensen similarity indices are used to assess the diversity of both individual samples and sites. For comparison with the present marshes, an index based on the TMAP vegetation typology was defined. Based on these methods, a selection of the individual samples was analyzed phytosociologically. It is found that all samples represent a mixture of vegetation types, but that the salt marsh species are a constant factor. The variation in the sample composition is not related to their dating, except for some of the latest samples that reflect the earliest endikements. Great similarity to the present marshes is found, but the analysis also testifies of a landscape profoundly disturbed by human activities throughout history.

INTRODUCTION | In the Wadden Sea mainland salt marsh area of both the Netherlands and Germany, there is a long tradition of studying plant remains from terps. A terp, also known as *Wurt/Warft/Wierde*, is an artificial dwelling mound usually erected on Holocene marine deposits and gradually elevated during its habitation history. Prior to the construction of dikes, terps guaranteed a safe haven for the local populations in times of severe floods. Ecologically, the area can be characterized as a salt marsh area.

This paper aims to presents an overview of archaeobotanical research carried out in the Dutch terp region so far, and re-evaluates the characterization of the former landscape. We show that the traditional description of the environment by archaeologists is much too simple and does not sufficiently acknowledge the huge variety of this vegetation. Especially substantial areas of brackish to fresh grasslands are hardly taken into account.

Several analyses are performed on the data to (1) gain insight in the diversity of past vegetation, (2) assess the role of time and space in this diversity, (3) define the common factor in the whole area, (4) define the degree of similarity to the present salt marsh landscape, and finally (5), evaluate the strengths and weaknesses of archaeobotanical data and their possible implications for nature conservation and management. These different aspects are highly interrelated and are therefore not dealt with individually, but involved in different parts of the discussion.

Because of the vastness of the region under study, both in time and space, there has not been aimed to fully reconstruct *the vegetation* surrounding the terps, as such a thing simply does not exist. Overviews of aspects of man's relation to and impact on the North Western European salt marsh environment in (pre)historic periods have been published from a variety of fields such as ecology, history, archaeology and geology (Bazelmans *et al*. 2012; Behre 2008, 58–130; Bromberg Gedan *et al*. 2009; Dijkema 1987; Doody 2004; Meier 2004; Oost *et al*. 2012; Rippon 2000). Studies dealing more specifically with past salt marsh vegetation have been presented for Northwestern Europe (Behre 1970, 1979, 1985; Körber-Grohne 1992; Van Zeist 1974), but also for example for North-America (Clark 1986) and Italy (Miola *et al*. 2010).

(Palaeo)-ecologists demonstrated the value of palaeobotanical sources for understanding present-day vegetation development, especially for mires where laminated peat sediments provide a direct insight into vegetation succession (Casparie 1972; Kooistra *et al.* 2006; Van 't Veer *et al.* 2000; Wheeler and Proctor 2000, 190). Unfortunately, the geomorphology and hydrology of salt marshes does not allow the formation for the halosere of neatly laminated sediments as peat provides for the hydrosere. A characteristic the salt marsh area does generally share with mires, however, is the excellent preservation of waterlogged plant remains, which allows a thorough analysis of past vegetation.

The relevance of studying past vegetation and human influence for present day nature conservation has recently received extra attention in the Netherlands (Schaminée and Janssen 2012; Schaminée and Weeda 2009). Bakker (2012, 250) states that 'Understanding the historical context of the developments of tidal salt marshes along intertidal flats is a prerequisite for any fruitful discussion about the perspectives of nature conservation and restoration in these systems'. Past vegetation can form a major contribution to this understanding. Although the present study is archaeobotanical in nature, some closing remarks with respect to the possible implications of this study's findings for salt marsh restoration and/or conservation are made at the end.

Research history | The foundations for this research in The Netherlands have already been laid out in the 19th century, by Acker Stratingh (1852) and Westerhoff (1871). The latter author published the first paper dealing exclusively with plant remains in the terp region. According to Beijerinck (1929, 11), they are to be considered the first 'more serious scholars' to deal with the subject. Today, it would be more appropriate to assign this qualification to Beijerinck himself. Perhaps better known for his classic 'Zadenatlas der Nederlandsche Flora' (seed atlas of the Dutch flora, 1947), he is the first to publish and depict a substantial number of species from a total of 16 different terps. As such, his work is the first that can be used even today as a reliable source of information, where the older studies should be mainly valued for their historic meaning. Following Beijerinck, overviews of the

archaeobotany in the Dutch terp region have been published by Van Zeist (1974) and briefly for comparison with the Heveskesklooster site by Cappers (1995b, 144-147).

A combination of renewed academic interest in terp archaeology and the rise of commercial archaeology in the Netherlands has resulted in a substantial and growing corpus of new data to see the light over the past two decades. However, these studies still heavily rely on a relatively small number of key publications from the second half of the 20th century. Although the present study deals primarily with the Dutch terps, two widely cited German site monographs must be mentioned here. It concerns Körber-Grohne's report of the plant remains from Feddersen Wierde (1967) and Behre's publication of Elisenhof (1976).

To gain insight into the vegetation surrounding the studied sites,three different approaches are applied in the terp region. Several authors combine these approaches to get a more complete model of the surrounding vegetation. The first approach is to divide the list of identified plant taxa in ecological groups such as 'grassland species' and 'aquatic plants' (e.g. Verbruggen 2012; Van Haaster 2005). Secondly, individual species values are applied to characterize the environment, which are ideally statistically combined with quantified samples (e.g. Cappers 1995b; De Roller 1999a). Finally, species can be manually ordered in the syntaxonomical system (e.g. Pals 1999; Van Zeist 1974; Van Zeist *et al*. 1987). This last approach is traditionally applied to sites as a whole, merging all samples from a site per archaeological time period.

METHODS | Demarcation of area and period | The construction of terps is a frequently opted for solution in different regions and periods of The Netherlands where periodic flooding took or takes place, both in the river and coastal areas. Because of the good preservation conditions in these wet areas, archaeobotany is generally included in archaeological research (e.g. Buurman 1999, West-Friesland; Van Dijk *et al*. 2011, Zeeland area; Van Smeerdijk *et al*. 2009, river area). This study however, focuses on the 'classic' terp region, situated in the present day provinces of Friesland and Groningen (Bazelmans *et al*. 2009, 6). The salt

marsh areas in these provinces are well-defined nowadays because of the presence of dykes. In the period prior to the systematic reclamation of the marsh areas, this boundary was much less clear, and a widespread transition zone between both fresh, brackish and saline environments, and cover sand, peat and marine deposits existed (Behre 2008, 73; Esselink *et al*. 2009, 3; see geomorphological maps of the area in Wiersma *et al*. 2009; Vos and Knol 2005). Although terps are also known from the peat area between the salt marshes and the Pleistocene hinterland, this area has poorly been studied so far. Recent research in Arkum (Bakker 2013) shows an initial phase of habitation in a 'peat landscape'. The peat deposits in this area are later buried under marine deposits, on which a terp was erected. Despite the fact that the initial phase cannot be characterized as a salt marsh environment, the botanical remains do testify to marine influence (Maurer 2013). In short, this study deals with all archaeobotanical and palaeobotanical studies of plant macro-remains from those areas in the provinces of Friesland and Groningen, where a marine influence to a certain extent can be demonstrated geologically and/or botanically.

Chronologically, this study begins at the first known exploitation of the marshes around 700 BC and continues until the 14th century. The construction of 'somewhat larger dykes' in the Frisian coastal area started around the 9th or 10th century AD (Bazelmans *et al*. 2012, 122; Bazelmans *et al*. 2009, 7). The rather general dates mentioned for some samples, often covering several centuries, would cause a substantial number of samples to be excluded should we adopt this date as an end date for the present study. The youngest possible date for a large number of samples dates back to the period between the 11th and 14th century. Generally, these samples still show a strong marine influence and are therefore still convincingly 'coastal'.

Sample and data selection | Firstly, a brief description of the most important archaeobotanical terminology and methodology for waterlogged samples in the terp region is presented here. During archaeological excavations in terps, a wide variety of features is identified. These features are predominantly man-made, such

as wells or houses, but they can also be natural creeks or vegetation layers. Within a feature, several 'fillings' can be identified. A good example of a feature and its respective fillings is a ditch. Following the initial construction, during alternating periods of flooding, heavy rainfall and more quiet periods, different layers of sediment will be deposited. Finally, if a ditch falls out of use for some reason, it is deliberately filled up with whatever was available, such as sods or dung. During excavation of this ditch, these various fillings can generally easily be identified on the basis of color or texture. If a soil sample is taken from a filling, the feature and the filling make up the 'context' of a sample. The soil samples are sieved, after which seeds, fruits and other diagnostic fragments are manually picked out and identified.

An overview was made of all sites where macrobotanical (remains >200 μm) research was carried out (Fig. 5.1 and Table 5.1). All samples were described in one matrix with presence/absence indicated for each species. The lack of dating and context information made Beijerinck's data (1929) unfit to be compared to the other samples in this overview. This means the oldest study included is by Van Zeist (1974). The inconsistency and poor documentation of sample method, sampling size, archaeological context, quantification methods, and proportion of a sample that has actually been studied, hamper an analysis on actual 'seed counts'. Furthermore, samples containing predominantly charred remains were excluded in this overview because profoundly different taphonomical processes affected their composition. Samples containing less than five taxa at the species level are also excluded, irrespective of the preservation condition. Amongst these were none that could ecologically be assumed to occur in this pure combination in one vegetation type (e.g. only *Salicornia europea* and *Suaeda maritima* in one sample).

Initially, taxa have been included in the dataset that have been identified to at least the genus level, including, as a separate taxon, uncertain identifications (cf), except for instances where they occurred in the same sample as a certain identification. This serves to gain insight into what species groups are apparently generally accepted to be difficult to identify. 'Type' identifications are omitted, except when they are included in the Dutch archae-

obotanical Database RADAR and specified there at the species level (Brinkkemper and Van Haaster 1995, version 2006). Combined taxa are split if they occur in more than twenty samples as such (e.g. *Atriplex patula/prostrata; Bromus hordeaceus/secalinus*). More incidental combined taxa and groups of more than two species are discarded (e.g. *Hordeum marinum/murinum; Carex acuta/elata/nigra/trinervis*).
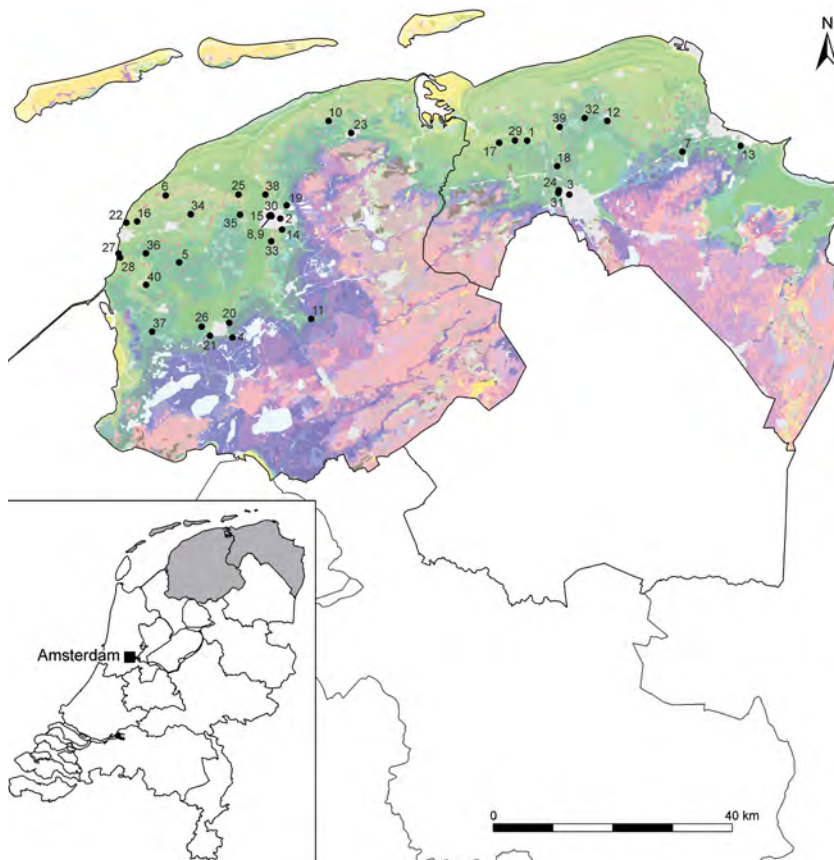
Figure 5.1 Location of the sites on a soil map of the northern Netherlands. Green tints: marine clay (former salt marsh); purple: peat area; salmon pink: Pleistocene sand area. Numbers correspond to Table 5.1. Figure by Chris Luinge

All identifications to the genus level are discarded unless the genus as a whole has ecological significance. These are generally genera with a limited number of species, except for *Potamogeton*. For example: *Galium, Mentha* and *Viola* are discarded, whereas

Lemna, Rhynchospora and *Zostera* are included in the analyses. For the genus *Agrostis* the decision was made to upgrade it to the species level. The extreme frequent occurrences in the samples legitimate the deduction that it mainly concerns *A. stolonifera*, a grass plant that is a characteristic of salt marsh vegetation.

Finally, all cultivated plants were removed from the dataset, since this paper focusses on the vegetation and crops are generally not included in the descriptions of arable weed vegetation types (e.g. Sissing 1950). All sites are numbered with respect to their year of publication, and all samples are labeled according to the main time period they fit in. The four time periods defined are: (1) before 100 B.C., (2) 100 B.C–400 A.D., (3) 400 A.D.-900 A.D., and (4) 900 A.D.–1400 AD. Sample groups were formed by combining all samples from the same period at one site. For the remainder of this paper, the abbreviations IS (individual samples) and SG (sample groups) are used where this is of relevance for understanding the analysis.

The only bryophyte genus included is *Sphagnum*. More detailed studies of mosses from terps have occasionally been undertaken (Van Zeist 1974, 238-264; Van Zeist *et al.* 1987, 419-424; Cappers and Van Zanten 1994).

	Site name	Reference	1	2	3	4	1/2	3/4	n	SG's
1	Ezinge	Van Zeist 1974	2						2	1
2	Leeuwarden	Van Zeist 1974	2						2	2
3	Paddepoel	Van Zeist 1974		10					10	3
4	Sneek	Van Zeist 1974		4					4	4
5	Tritsum	Van Zeist 1974					16		16	5
6	Tzummarrum	Van Zeist 1974			6				6	6
7	Schildmeer area	Bohncke 1984	9	6	3				18	7 / 8 / 9
8	Leeuw. Gouverneursplein	Van Zeist *et al.* 1987				19			19	10
9	Leeuw. Speelmansstraat	Van Zeist *et al.* 1987			1	8		1	10	11 / 12 / 13
10	Foudgum	Van Zeist *et al.* 1987				5			5	14
11	Oldeboorn	Van Zeist 1988a				3			3	15
12	Middelstum	Van Zeist 1989	6						6	16
13	Heveskesklooster	Cappers 1995b		19		24			43	17 / 18

No.	Site	Reference	1	2	3	4	Total	SG
14	Hempens-Teerns	De Roller 1999a		9			9	19
15	Leeuw. Bollemanssteeg	De Roller 1999b			2		2	20
16	Wijnaldum	Pals 1999			4		4	21
17	Aalsum	De Roller 2000			1		1	22
18	Baflo	De Roller and Korf 2002		1	7		8	23 / 24
19	Leeuwarden Bullepolder	De Roller 2002a		6			6	25
20	Sneek, stadsrondweg	De Roller 2002b		7			7	26
21	Sneek, Tinga	De Roller 2002c			1	2	3	27 / 28
22	Harlingen Boltastate	De Roller 2002d			1		1	29
23	Dokkum	Van Haaster *et al.* 2003			3		3	30
24	Friesestraatweg	Cappers *et al.* 2005		14			14	31
25	Beetgumermolen	Van Haaster 2005			3		3	32
26	Sneek Stinswier	Hänninen and Van Waijen 2005			4		4	33
27	Heegewiersterfjild	Van Haaster 2006b		1			1	34
28	Kimswerd	Van Haaster 2006b			7		7	35
29	Englum	Nieuwhof and Woldring 2008	3	5			8	36 / 37
30	Oldehoofsterkerkhof Leeuw.	Cappers 2008; Kuijper 2008	2	18	23		43	38 / 39 / 40
31	De Held	Vrede *et al.* 2010			4		4	41
32	Onderdendam	Schepers 2010		2			2	42
33	Goutum	Out and Kaaijk 2010	4				4	43
34	Peins	Nieuwhof 2012		24	4		28	44 / 45
35	Marssum	Verbruggen 2012; Schepers 2012a	2	1			3	46 / 47
36	Achlum	Schepers in prep.		1	1		2	48 / 49
37	Arkum	Maurer 2013	1	10			11	50 / 51
38	Jelsum	Van der Laan 2013a	5				5	52
39	Winsum	unpublished data			4		4	53
40	Witmarsum	Schepers 2012c			1		1	54

Table 5.1 All sites included in the present study and the number of samples studied per site per period. 1=before 100 B.C., 2=100 B.C.-400 A.D., 3=400 A.D.-900 A.D., 4= 900 A.D.-1400 A.D. 'Leeuw.'=Leeuwarden (site 8 and 9). SG's are compiled of the combination of all samples from one period per site and numbered uniquely. For the location of the sites, compare to Figure 5.1

Types of analyses applied | Seriation was performed on the individual samples using PAST (Hammer *et al.* 2001), to acquire a two-dimensional quick insight in the variation in sample composition and to illustrate the difference between ecological and archaeobotanical data. Environmental values for all species were adapted from indicator values and values taken from the ecological species groups for the Netherlands and Flanders (Ellenberg *et al.* 1991; Runhaar *et al.* 2004). Based upon the individual species values, environmental values for the IS' and the sample groups were calculated. The CANOCO program was used to perform principal component analysis to explore the relation between the environmental variables and the IS/SG's (Ter Braak and Šmilauer 2002). Species richness, sample context, and chronology are also taken into account here.

Sørensen similarity indices for all IS and SG's were calculated in SPSS (version 20, 2011). By taking an average of all Sørensen indices for each IS and each SG, the most average IS and SG's were defined.

A 'salt marsh' index was calculated with the help of a new vegetation typology for salt and brackish vegetation, as defined by the Trilateral Monitoring and Assessment Program (TMAP vegetation typology, Esselink *et al.* 2009). This TMAP-index is calculated from the ratio between the number of species from this typology in an IS or SG and the total number of TMAP typology species identified in all terp samples (Esselink *et al.* 2009). Species frequently found in archaeobotanical samples but not present in this system are judged in detail and compared to their present day distribution to assess whether they are frequently occurring Dutch mainland Wadden sea salt marsh species that are not a part of the TMAP typology or species indeed more common in this area in the past (Anon. 2011; Hennekens *et al.* 2010; Jager and Rintjema 2011). A brief commentary will be given to TMAP species not found in archaeobotanical samples or in considerably lower frequencies than one would expect given their present-day distribution.

Based on all of the above, a subset of IS was selected to be analyzed phytosociologically with a recently developed method to identify past vegetation (PALAEOASSOCIA, Schepers *et al.*

2013b). The subset of IS includes both extreme and more average examples. This analysis uses the co-occurrence of plant taxa based on (sub) modern inventories of vegetation. The nomenclature of the syntaxonomy follows Schaminée *et al.* (1995a, 1995c, 1996, 1998) and Stortelder *et al.* (1999). For the ecological interpretation of the results, the digital counterpart of these volumes, as well as the field guide for Dutch plant communities were also used (Hennekens *et al.* 2010; Schaminée *et al.* 2010).The generated overview of the vegetation diversity will be used to evaluate former exploitation possibilities in the area as well as the former impact of man on the salt marsh environment.

RESULTS | Gathering data | The choice to include taxa in the way they were initially mentioned in the source publications, including uncertainties on different taxonomic levels, resulted in a total of nearly 600 different taxa in the initial dataset. The most troublesome genus with respect to identification is Carex (represented by 40 entries). The large number of species within the genus makes certain identification on the species level problematic, despite a number of available keys and atlases (e.g. Berggren 1969; Huntley 2012). After removing uncertain identifications and identification groups, seventeen Carex species remain. Other wild plant taxa frequently occurring with uncertainties on the species level are *Potamogeton, Ranunculus* subg. *Batrachium, Persicaria* and *Potentilla*. After removing of crop plants, uncertain identifications and all samples containing less than five taxa, a total of 307 taxa and 332 individual samples (IS) remained (Table 5.1). The complete sample information can be found in the electronic supplementary material of the online version of this paper. Some of the crop plants removed are currently listed in the Dutch flora. The decision to keep or discard these species depends on whether or not they are listed in the ecological species groups for the Netherlands and Flanders (Runhaar *et al.* 2004). Although all calculations and indices presented in this paper are based on this reduced list, the 'raw' matrix with almost 600 possible taxa will be referred to in the discussion section where it can provide extra clarity. For the chronological subdivision of the IS in SG's we accepted an overlap of one century into another period. Where this

overlap was more or where the sample was dated within two centuries on the border of two periods the sample is assigned a double period indication (sites 5, 9 and 21). In total 54 SG's were formed.

Seriation | Seriation of the sample (IS) illustrates a clear and important difference between archaeobotanical data and data from vegetation relevées (Fig. 5.2). In synoptic tables of vegetation relevés, seriation of all data will result in a clustering of points more or less along the diagonal. In salt marsh ecosystems, this will mainly result in a figure in which the gradual transfer from the pioneer marsh zone to the brackish or fresh grasslands higher up can be recognized. Some 200 terp samples are taken from ditches, dung layers and wells [1].
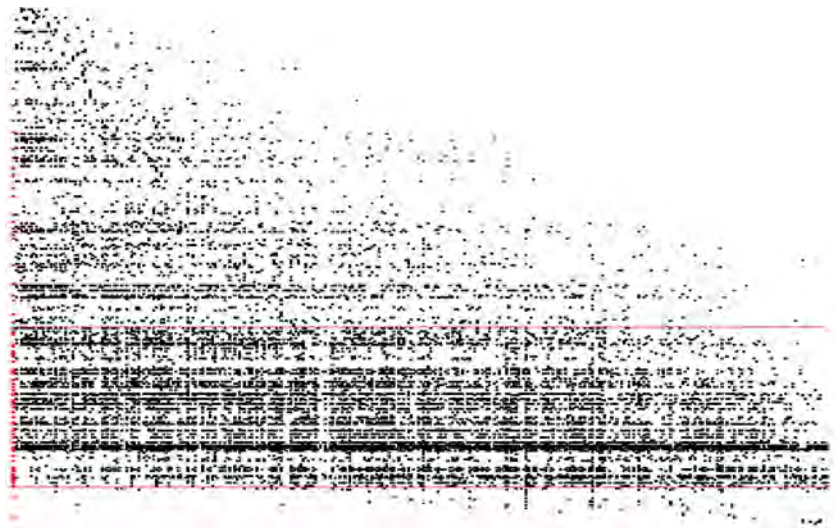
Figure 5.2 Seriation of 332 waterlogged samples (IS)(columns) and 307 plant taxa (rows) from the Dutch terp region. The red dots in the far left column indicate species present in the TMAP vegetation typology (Esselink *et al.* 2009, see Table 5.3). The cluster of salt marsh species near the bottom of the matrix is fringed with two red lines

One could state that the tradition is to select especially those contexts for sampling that visually appear to have a high organic component. These samples frequently (but not always) turn out to contain species from a variety of different plant communities. As a result, a number of plant species is present in the majority of the samples, whereas other species occur more incidentally (Fig.

5.2). We indicated the species from the TMAP vegetation typology on the left side of the matrix, clearly showing that these are generally amongst the more frequent encountered species in the samples, clustering near the bottom. This illustrates the validity of labeling the terp region, as a whole, a salt marsh ecosystem. The salt marsh is always present and the salt marsh species are thus a constant factor.

Principal Component Analysis | We choose to use the system by Runhaar *et al.* (2004) to calculate environmental values for the samples because, unlike the indicator values as defined by Ellenberg *et al.* (1991), it enables the direct calculation of a value for vegetation structure. The ordination diagram of all IS shows a relation between salinity and sample size as well as a clear difference between the samples from the period 1–3 and the samples from period 4 (Fig. 5.3a). As the total number of saline and brackish species is much lower than the number of fresh species, samples with many species will always turn out relatively fresh. The more species rich samples containing a high number of salt marsh species are depicted at the bottom right of the diagram, but the species rich samples in the top right of the diagram, correlating with period 4 and 'fresh water' also still contain salt marsh species. The relatively short length of the arrows for the periods 1–3 indicates that these periods explain very little of the shown variation. When the SG's are shown instead of the individual samples, the picture does not differ much (Fig. 5.3b). First of all, the longer arrow for period 1 towards 'brackish' indicates that the earliest period is least influenced by fresh species. The 'moist' arrow in this diagram is not shown, because it overlaps practically completely with the arrow indicative of dry conditions. It also shows that the top right cluster of species rich individual samples (IS) in Figure 5.3a is linked with five sample groups (SG). That these SG's clearly represent a separate group in comparison to the other samples, is confirmed by the position of the 'most average' samples according to the highest average Sørensen similarity index (Fig. 5.3c, see below). Remarkably little patterning is visible with respect to the archaeological context (Fig. 5.3d). Only a part of

the samples designated as natural context shows a cluster on the left of the diagram. These samples all belong to the Schildmeer area (site 7).
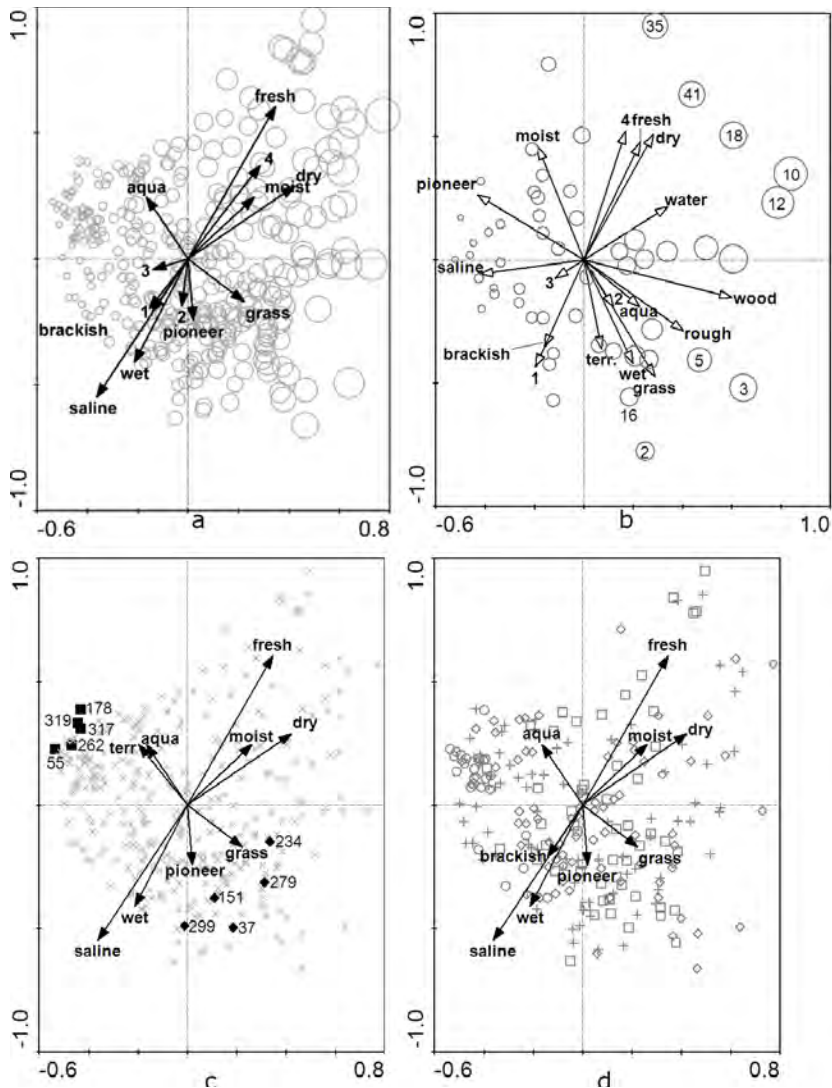
Figure 5.3 PCA ordination diagrams of archaeobotanical terps samples. Arrows labelled with numbers 1-4 indicate the time period (Table 5.1). The environmental variables shown were chosen for both the interpretational value and the readability of the diagram. a: all samples (IS), symbol size indicates number of species. b: sample groups (SG), symbol size indicates number of species. Numbers within or below symbol indicate SG number (Table 5.1). c: five highest (diamonds) and lowest (squares) average Sørensen similarity indices for all IS. d: four main IS context types. Diamond=well, square=dung, cross=ditch, circle=natural. Samples from other contexts are not shown

Sørensen similarity index | The three SG's from the Schildmeer area (SG 7, 8 and 9; site 7) are also among the five lowest average Sørensen similarity indices (Table 5.2). These samples were taken from salt marsh (vegetation) layers not directly associated with a terp excavation (Schoute 1984). That a SG from Arkum (site 37) falls in between the values of the Schildmeer SG's does nót mean that these SG's are alike. The only character they share is a strong average dissimilarity to all other SG's. The most remarkable outcome of the index is that SG's from all four periods are present amongst both the top and bottom ten average values. With respect to the ten most similar SG's, two sites (Oldehoofsterkerkhof, no.30; Peins, no.34) are represented by two SG's (no. 39 and 40; no. 44 and 45). On a geographical level, it should be noted that sites 14, 19 and 30 all originate from the vicinity of the present day city of Leeuwarden. Some other sites near Leeuwarden however, differ more and the other sites represented in the top ten represent various regions.

There is a relation between the number of species in a SG and its average similarity to the other SG's. SG's within the top ten range between 48 and 82 species with an average of 66. The bottom ten SG's range between 9 and 52 species, with an average of 21. SG's with more species share many species with most others and, consequently, have a relatively high similarity index too; however, they also have more species not present in most other SG's which causes them not to end up in the top ten. There is only one site from the present province of Groningen represented in the top ten SG's. More research in Groningen will have to confirm whether this is a real difference.

Comparison to the Trilateral Monitoring and Assessment Program (TMAP) vegetation typology | Differences between archaeobotanical data and present data necessitated several choices for comparison between the TMAP vegetation typology and plant data from the terps. *Zannichellia palustris* s.l. is divided into two subspecies, for these can generally be distinguished archaeobotanically. On the other hand, *Salicornia europeae* and *Taraxum officinale* in archaeobotanical samples should be regarded identifications sensu lato. Fresh seeds of *Salicornia* might be distinguishable

	34 44 0,53	30 40 0,53	30 39 0,53	14 19 0,53	6 6 0,53	4 4 0,52	10 14 0,52	12 16 0,51	19 25 0,51	34 45 0,5	
44	1,00	0,69	0,73	0,69	0,64	0,62	0,62	0,62	0,66	0,64	
40		1,00	0,78	0,63	0,61	0,60	0,64	0,62	0,62	0,55	
39			1,00	0,64	0,65	0,64	0,62	0,61	0,60	0,58	
19				1,00	0,62	0,66	0,64	0,58	0,66	0,59	
6					1,00	0,67	0,70	0,70	0,56	0,65	
4						1,00	0,66	0,71	0,62	0,56	
14							1,00	0,65	0,68	0,59	
16								1,00	0,61	0,55	
25									1,00	0,57	
45										1,00	
42											
30											
27											
54											
46											
34											
7											
8											
50											
9											

Table 5.2 Sørensen similarity indices given for the top and bottom ten SG's selected according to their overall mean index values. Left of dashed line: ten SG's with highest mean similarity values; right of dashed line: ten SG's with lowest mean similarity values. Top row: site number. Second row SG number. Third row mean index over all SG's. Compare to Table 5.1

by the density of hairs, but in archaeological material their appearance can strongly be influenced by erosion (Joenje 1982; Van der Meijden 2005, 309).

Furthermore, *Odontites vernus* cannot be identified to the subspecies level, but is accepted as a match to *O.vernus* subsp. *serotinus* here. A total number of 75 taxa from the terps samples are matched to the TMAP typology, some occurring in multiple

32	23	21	40	35	27	7	7	37	7
42	30	27	54	46	34	7	8	50	9
0,38	0,36	0,34	0,34	0,31	0,31	0,3	0,3	0,22	0,22
0,41	0,39	0,41	0,40	0,33	0,33	0,30	0,29	0,16	0,20
0,40	0,45	0,34	0,33	0,30	0,25	0,29	0,27	0,18	0,15
0,41	0,42	0,37	0,38	0,31	0,29	0,29	0,27	0,22	0,16
0,43	0,40	0,39	0,40	0,34	0,30	0,36	0,33	0,19	0,26
0,35	0,34	0,43	0,36	0,41	0,31	0,28	0,25	0,13	0,18
0,45	0,36	0,35	0,31	0,33	0,32	0,38	0,34	0,21	0,22
0,28	0,34	0,35	0,27	0,27	0,27	0,29	0,25	0,18	0,19
0,40	0,38	0,41	0,28	0,32	0,24	0,32	0,31	0,16	0,20
0,37	0,34	0,35	0,30	0,32	0,30	0,36	0,30	0,20	0,23
0,38	0,42	0,41	0,39	0,42	0,37	0,30	0,31	0,21	0,20
1,00	0,36	0,39	0,51	0,25	0,37	0,30	0,42	0,33	0,29
	1,00	0,19	0,34	0,20	0,20	0,21	0,17	0,23	0,15
		1,00	0,32	0,26	0,27	0,22	0,32	0,21	0,18
			1,00	0,16	0,34	0,14	0,23	0,37	0,19
				1,00	0,33	0,32	0,33	0,14	0,25
					1,00	0,33	0,41	0,15	0,33
						1,00	0,76	0,24	0,63
							1,00	0,31	0,53
								1,00	0,27
									1,00

categories (Table 5.3). A relative TMAP index was calculated from the ratio between the total number of taxa in an IS or SG and the number of TMAP taxa (Table 5.4). An absolute TMAP index was calculated from the ratio between the maximum possible number of TMAP taxa (74) and the number of TMAP taxa in an IS or SG.[2] For the relative TMAP index the number of species in the IS and SG's is also shown. On average, IS and SG's with high relative TMAP indices have fewer species than those with a low index. This effect, however, is much less dramatic for IS than for SG's. For the absolute TMAP index, it can be observed that within the top ten scores for the SG's, three sites groups are

present which are amongst the bottom ten in the relative index (10, 17 and 18). This is the simple consequence of the fact that species rich samples in the terp region are likely to contain both a high number of species typical for the salt marsh, as well as a high number of other species. Low relative TMAP indices are indicative of substantial differences between the present day salt marsh landscape and the former terp landscape. This is especially true for IS with a relatively high number of species, such as 84 and 188 (49 and 41 species respectively).

Code	Taxon
A	Potamogeton pectinatus (20/9), Zannichellia palustris subsp. pedicellata (17/6), Ruppia maritima (8/6), Zostera (7/2), Zostera noltii (3/2), Zostera marina (2/1), Zannichellia palustris subsp. palustris (1/1)
P	Suaeda maritima (181/45), Salicornia europaea s.l. (155/35)
L	Triglochin maritima (255/47), Spergularia salina (166/35), Aster tripolium (150/38), Spergularia media subsp. angustata (142/27), Plantago maritima (124/31), Limonium vulgare (66/27), Puccinellia maritima (51/24), Parapholis strigosa (2/2)
H	Atriplex prostrata (304/52), Juncus gerardi (279/48), Agrostis stolonifera (222/43), Potentilla anserina (204/44), Poa pratensis (182/37), Glaux maritima (169/35), Leontodon autumnalis (152/38), Atriplex littoralis (137/35), Odontites vernus (109/26), Trifolium repens (93/22), Festuca rubra (93/24), Rumex crispus (90/33), Ranunculus repens (71/24), Armeria maritima (53/22), Elytrigia repens (49/13), Elytrigia atherica (40/10), Carex distans (37/11), Lolium perenne (23/9), Carex extensa (23/8), Trifolium pratense (21/10), Plantago coronopus (10/7), Hordeum marinum (8/5), Bupleurum tenuissimum (4/4), Leontodon saxatilis (3/3), Hordeum secalinum (2/1), Sagina maritima (2/1), Cochlearia danica (1/1)
B	Bolboschoenus maritimus (229/45), Agrostis stolonifera (222/43), Potentilla anserina (204/44), Leontodon autumnalis (152/38), Chenopodium rubrum (142/39), Chenopodium glaucum (133/37), Phragmites australis (94/30), Trifolium repens (93/22), Juncus bufonius (90/25), Alopecurus geniculatus (79/26), Ranunculus sceleratus (72/20), Oenanthe lachenalii (70/22), Schoenoplectus tabernaemontani (71/21), Juncus articulatus (46/15), Elytrigia repens (49/13), Eleocharis uniglumis (23/8), Apium graveolens (17/12), Triglochin palustris (6/4), Blysmus rufus (1/1)
X	Agrostis stolonifera (222/43), Glaux maritima (169/35), Beta vulgaris subsp. maritima (1/1), Cakile maritima (1/1)
F	Polygonum aviculare (227/47), Plantago major (219/41), Poa trivialis (171/35), Poa annua (74/24), Elytrigia repens (49/13), Cirsium arvense (46/18), Rumex obtusifolius (44/18), Capsella bursa-pastoris (40/18), Taraxacum officinale s.l. (30/17), Lolium perenne (23/9), Cynosurus cristatus (1/1)
S	Taraxacum officinale s.l. (30/17), Carex oederi (25/5), Eupatorium cannabinum (15/6), Linum catharticum (14/7), Pedicularis palustris (5/3), Carex flacca (1/1), Eleocharis quinqueflora (1/1)

T	Atriplex patula (310/53), Stellaria media (201/44), Chenopodium ficifolium (189/39), Sonchus asper (176/40), Chenopodium album (172/41), Persicaria lapathifolia (135/40), Puccinellia distans (121/27), Ranunculus sardous (119/31), Eleocharis palustris (116/26), Urtica urens (106/34), Tripleurospermum maritimum (100/28), Sonchus arvensis (94/31), Carex otrubae (80/25), Sonchus oleraceus (80/26), Solanum nigrum (80/25), Urtica dioica (72/26), Sinapis arvensis (70/16), Erica tetralix (60/22), Mentha aquatica (60/21), Carduus crispus (57/14), Medicago lupulina (53/19), Bromus hordeaceus (51/20), Carex vesicaria (51/19), Bromus secalinus (47/19), Rumex acetosella (47/18), Euphorbia helioscopia (46/19), Raphanus raphanistrum (46/19), Persicaria maculosa (45/15), Calluna vulgaris (43/18), Brassica rapa (42/16), Carex rostrata (41/14), Mentha arvensis (38/12), Anagallis arvensis (38/19), Carex acuta (36/14), Typha (35/14), Hyoscyamus niger (34/15)

Table 5.3 Taxa identified in the archaeobotanical samples included in the TMAP typology (Esselink et al. 2009). A=aquatic, P=pioneer zone, L=low salt marsh, H=high salt marsh, B=brackish marsh, X=embryonic dunes and driftlines, F=fresh anthropogenic grasslands, S=seepage vegetation. The T category is compiled out of all species not in the TMAP typology, but present in over 10% (>33) of all terps samples. The species are ordered according to the number of individual samples (IS) in which a species occurs (between brackets, the number behind the slash indicates the number of SG's)

no.	TMAP Species	Total Species	relative TMAP index		no.	TMAP Species	absolute TMAP index
Top ten value IS					**Top ten value IS**		
290	6	6	1,00		117	39	0,53
296	9	9	1,00		9	37	0,50
305	5	5	1,00		193	37	0,50
153	15	17	0,88		4	34	0,46
263	7	8	0,88		3	33	0,45
291	7	8	0,88		12	33	0,45
137	20	23	0,87		60	33	0,45
300	20	23	0,87		116	33	0,45
30	17	20	0,85		135	33	0,45
146	21	25	0,84		195	33	0,45
Top ten value SG's					**Top ten value SG's**		
46	15	19	0,79		3	51	0,69
27	14	20	0,70		17	48	0,65
11	27	40	0,68		10	45	0,61
36	20	30	0,67		18	45	0,61
47	18	27	0,67		5	44	0,59

23	23	35	0,66	12	44	0,59
6	35	54	0,65	41	44	0,59
34	11	17	0,65	31	43	0,58
45	31	48	0,65	14	41	0,55
38	16	26	0,62	25	40	0,54

Bottom ten value IS				Bottom ten value IS		
260	2	8	0,25	58	2	0,03
178	4	15	0,27	260	2	0,03
188	12	41	0,29	55	3	0,04
320	5	17	0,29	57	3	0,04
205	4	13	0,31	264	3	0,04
317	4	13	0,31	312	3	0,04
187	8	25	0,32	319	3	0,04
84	16	49	0,33	321	3	0,04
58	2	6	0,33	56	4	0,05
312	3	9	0,33	145	4	0,05

Bottom ten value SG's				Bottom ten value SG's		
30	15	52	0,29	50	3	0,04
10	45	141	0,32	9	7	0,09
12	44	136	0,32	54	7	0,09
50	3	9	0,33	8	10	0,14
51	15	42	0,36	42	10	0,14
35	38	104	0,37	34	11	0,15
26	31	80	0,39	7	13	0,18
54	7	18	0,39	22	13	0,18
17	48	119	0,40	27	14	0,19
18	45	111	0,41	30	15	0,20

Table 5.4 Relative and absolute TMAP-indices for the bottom and top ten IS and SG's

Palaeoassocia | The PALAEOASSOCIA analysis methodology for the identification of plant communities is too complex and multi-faceted to apply to all IS. Therefore, it is not used here as an instrument for a complete vegetation reconstruction of the entire terp region over the whole period under study, but to identify the variety of plant communities that must have been present in the terp region, thus establishing a general view of the vegetation diversity. A selection of IS was made on the basis of the different analyses presented above (Table 5.5). For each category, all samples analyzed are from different sites and contain at least ten species. The more frequently identified plant communities as well as a number of syntaxa from less present classes and orders will be briefly described here. Sporadically occurring communities from well represented classes are ignored.

The strongest represented vegetation type within the categories 1, 2 and 4 is the *Chenopodietum rubri*, especially in category 1 dominated by the brackish subassociation *spergularietosum*, which is also well represented in categories 3 and 5. According to Schaminée *et al*. (1998, 189-192), the association is indicative of brackish conditions and trampled places near the entrance of meadows. On the association level, it is by far the best represented pioneer community. It is often found in zonation with the *Puccinellio-Spergularion salinae*, which includes the *Puccinellietum distantis* association. This association is dominant in category 3 and well represented in categories 1 and 4. It thrives in recently reclaimed polders and in the outer dyke area at trodden places or where sods have been cut, but the subassociation specifically related to these activities (polygonetosum) is not very well presented (Beeftink 1965, 115; Schaminée *et al*. 1998, 11). When disturbance ceases, the association is replaced by the *Puccinellietum maritimae* or the *Armerion maritimae*.

The *Puccinellietum maritimae parapholidetosum* is well represented in categories 1 and 3. It occurs on sandy subsoil, and is characterized by strongly fluctuating salinity (Schaminée *et al*. 1998, 102-105). The *Armerion maritimae* is less well presented, except in category 5, where the relatively wet *Junco-Caricetum extensa* dominates. This association is largely restricted to the Wadden islands nowadays, occurring mainly on sandy subsoils.

If more silt is deposited, it is often succeeded with the *Juncetum gerardii*, which is identified in categories 1, 3 and 5.

Sample	Site	Selection criterion	Category
37	6	top 5 average Sørensen	1
114	13	top 5 average Sørensen	1
151	14	top 5 average Sørensen	1
234	30	top 5 average Sørensen	1
299	34	top 5 average Sørensen	1
9	3	top 3 TMAP absolute	2
117	13	top 3 TMAP absolute	2
193	24	top 3 TMAP absolute	2
137	13	top 3 TMAP relative	3
153	14	top 3 TMAP relative	3
300	34	top 3 TMAP relative	3
51	7	top 3 dry	4
71	8	top 3 dry	4
156	16	top 3 dry	4
110	13	top 3 wet	5
276	33	top 3 wet	5
42	7	top 3 wet / bottom 3 average Sørensen	5/6
178	20	bottom 3 average Sørensen	6
317	37	bottom 3 average Sørensen	6

Table 5.5 Samples analyzed phytosociologically through palaeoassocia and the reason for selection in 6 categories. Compare categories 2 and 3 to IS with at least ten species and originating from different sites in Table 5.4

A final plant community to be mentioned because it is well supported by the analysis is the *Lolio-Potentillion anserinae*. Within this alliance, the associations *Triglochino-agrostietum stoloniferae* as well as the *Trifolio fragiferi-Agrostietum stoloniferae* were identified. These plant communities are indicative of annually inundated moderately grazed meadows on the higher parts of the salt marsh (Schaminée *et al*. 1996, 34). The associations are found in proximity of the aforementioned *Armerion maritimae* and the *Bidention tripartitae*.

In addition to plant communities from classes already mentioned, plant communities of wet communities in fresh to brackish conditions are well presented in category 6. It concerns the classes *Littorelletea, Phragmitetea* and *Parvocaricetea.*

Finally, it should be mentioned here that the *Chenopodietum rubri* is dominant in category 4, but that several communities indicative of cultivated fields and other anthropogenically disturbed environments are suggested as well (classes *Stellarietea mediae* and *Artemisietea vulgaris*).

DISCUSSION | The present analysis confirms that the former terps region is a salt marsh ecosystem, in line with the findings of previous studies. Especially non-specialist 'cultural archaeologists' however, tend to overemphasize the role salinity played. Although brackish grasslands and even fresh anthropogenic grasslands are accepted parts within the present salt marsh area in its wider sense (Esselink *et al.* 2009), little attention is paid to that in archaeology. Especially the higher parts of the marsh, where the terps were situated, need not be that saline throughout the whole year. Where ecologist realize this when they use the phrase 'salt marsh' or 'salzwiesen', archaeologists undervalue the implications of this variation on a local scale. On a methodological level, it is shown that applying types of analysis hardly used in archaeobotany to the data, allows new insights on past landscape while using 'classic' find categories such as plant macro-remains. Noteworthy is the apparently negligible influence chronology plays, except for the latest phase. This is beyond doubt related to the fact that a substantial number of the samples from this phase date later than the first permanent embankments, which caused a rapid desalination.

Data | As stated in the introduction, terps are generally characterized by good preservation conditions for waterlogged plant remains. A more diverse image of the landscape and the vegetation in this widespread area seems appropriate as this characterization is not true for all terps. At Lutjelollum, for instance, poor preservation conditions obscured botanical research completely; whereas, research on the terps of Tzummarrum and Wijnaldum

was largely restricted to charred remains (Mulder and Ufkes 2007; Pals 1999; Van Haaster 2006a).

Data produced by archaeobotanists over the past forty years enables a detailed thorough insight into the vegetation diversity of the terp region in the past. On individual species level, some observations should be interpreted as a result of which scholar performed the research rather than an actual difference in the past vegetation. *Sagina maritima* for example, has only been identified twice and on one particular site. Most authors, also outside the terp region, only identify *Sagina* seeds to the genus level (data from RADAR, Van Haaster and Brinkkemper 1995, version 2006). The identification of notoriously 'difficult' groups such as *Carex* spp and some wild Poaceae species will be strongly influenced by the quality of the available reference collection as well as the amount of time available to the researcher. In this paper, all identifications are accepted as such from the original report, however doubtful they may be, for it is impossible to critically assess all individual identifications. The overall picture suggests that these minor differences in identification tradition between analysts or groups hardly influence the results. The PCA plots do not cluster the studies performed by different scholars in separate groups and both the TMAP index and the Sörensen similarity index display a variety of SG's and IS from different authors in the top and bottom ten.

The decision to convert all available samples to presence/absence data is, as stated in the introduction, led by the finding that several studies insufficiently specify the exact sampling, processing, identification and/or quantification methods used in the analysis, which is a problem identified early on in the field of archaeobotany by Van der Veen and Fieller (1982). Differences in sample size are likely to distort the overall results more if presence/absence data are used (Jones 1991, 64). The high amount of samples involved in this study, however, probably diminishes this effect. Moreover, incomplete or incorrect description of the archaeological context hampers insight in formation processes behind the sample composition, a prerequisite for any quantitative analysis (Van Haaster 2008, 8). The translation of seed numbers in species abundance is highly complex and influenced by

many factors that cannot be identified anymore (Cappers 1995a; Dieffenbacher-Krall 2007). Nonetheless, quantification has proven valuable for showing developments over time on the site level in the terp region (e.g. Bohncke 1984; Cappers 1995b; Van Zeist *et al.* 1987).

With respect to the representativeness of the samples analyzed here for the whole former Dutch salt marsh area, it needs to be stressed that archaeobotanical samples are mostly taken from archaeological features and within a former settlement. Cappers (1994, 152) illustrates that this leads to an over-representation of ruderal and arable weed species as compared to, for example, species of woodland and dry grasslands. Hence, the environment on the terp proper differed from the surrounding marshes by both the absence of flooding and a high degree of disturbance. The off-site vegetation of the past salt marsh area is thus largely represented by plant remains carried into the settlement by a wide variety of human activities such as cutting sods, trampling, harvesting crops , and herding of cattle and sheep. Plant remains are also deposited by drift litter on the edge of the terps by flooding. That the immediate surroundings of the terp were atypical of the salt marsh, is confirmed by the fact that that no match could be found between the beetle fauna of the present marsh and beetle remains found in archaeobotanical samples dominated by salt marsh plant species (Thasing *et al.* 2012). Evidently, these plants (parts and their remains) must therefore have been carried in from further away, leaving the beetles in their source area.

Archaeobotanical samples rarely reflect only a single plant community and many factors influence the species composition of archaeobotanical samples (Cappers 1995a; Dieffenbacher-Krall 2007; Willerding 1991). When an archaeobotanical sample does indeed reflect only one past vegetation type, the sample is labeled as a pure sample ('*reine Probe*'), originating from a so-called palaeobiocoenose (Willerding 1991; Körber-Grohne 1967). Samples identified as such were recovered from pure organic layers dominated by *Bolboschoenus maritimus, Phragmites australis* or *Juncus gerardi* in the German terp of Feddersen wierde (Körber-Grohne 1967). According to Behre (1970, 35), samples

representing one growth location or plant community are not uncommon '*in gutem Wurtenmaterial*'. However, seriation performed on the Dutch data, shows that taxa indicative of various salt marsh zones occur together in most of the samples, often mixed in with plants from other environments. Organic layers, like at Feddersen wierde, clearly representing pure various forms of *Juncetum gerardi* or *Phragmition australis* communities are not found in the Dutch terp region. Although also in Germany, most samples contain a mixture of plants from different origins (e.g. Behre 1991), the total absence of pure samples in the Dutch terps is a real and significant difference. Therefore, our interpretation of the vegetation is based on the disentanglement of these species by the variety of methods presented above.

Reconstruction of vegetation on and around the terps | The expected dominance of ruderal vegetation in the archaeobotanical analysis is confirmed. A closer look at category (T) in Table 5.3 reveals that the list of plant species commonly found in terp samples, but not part of the TMAP vegetation typology, consists, for a great part, of ruderal species, which are common in disturbed places in modern salt marshes as well, such as *Stellaria media*, *Sonchus asper*, and *Urtica dioica*. The variety of IS in which these occur, as well as the frequency in which they occur, suggest that these species cannot all be accounted for by the vegetation on the terp. Behre (1991, 155) states that plant communities from the *Artemisietea vulgaris*, ruderal communities, were present on the terps and in the surrounding environment. Ruderals would have been a common sight indeed in the wide surroundings of the terp, as a result of intensive use of the landscape. This includes cultivation of a number of crops, amongst which hulled six-row barley (*Hordeum vulgare* ssp. *vulgare*), linseed (*Linum usitatissimum*) and faba bean (*Vicia faba*) are the most common. Behre (1976) identifies *Stellarietea mediae* communities for the German marshes, which fits into the argument supporting local cultivation. Additionally, through the evidence of 'plough layers' in the field on several sites, it has been derived that crops were cultivated locally and not all imported from outside the terp region (Tuinstra and Van Malssen 2010; Bazelmans *et al*. 1999). Van Zeist (1988b)

also concludes that the import of grains and wild plant products from outside the salt marsh region should not be over-estimated. The scale of the local cultivation is hard to assess. According to Gerrets (2010, 111), the importance of cultivation should 'not be exaggerated', but he presents very little to support this suggestion. Despite the large number of potential arable weed species identified, typical Stellarietea mediae communities are poorly represented in the phytosociological analysis. This is partially caused by the choice to exclude charred seed assemblages, frequently including cereals, from the present analysis. However, what plays a bigger role here is the current absence of a arable weed community indicative for cultivation in a salt marsh environment. All archaeobotanical analysis uses present botanical data for the interpretation of the past, known as the 'uniformitarian assumption'. Plant communities lacking a modern analogue are likely to occur in the past. Considering climatic conditions have changed minimally since the period under study, these differences will be most dramatic when changing human behavior is involved. With respect to cultivation in a salt marsh environment, this involves many different factors, which can be divided in two main categories. Firstly, the current salt marsh area is not at all used for cultivation on any scale. Secondly, should cultivation in a salt marsh environment still be carried out, differences in agricultural practices such as ploughing and fertilizing methods would still lead to non-analogue plant communities (see also Schepers *et al*. 2013b and references therein). Several studies of charred grain assemblages in the terp region show that, besides typical arable weeds, several marsh species such as *Glaux maritima* and *Bolboschoenus maritimus,* were part of the weed flora (Pals 1999; Van Haaster 2006a; Van Zeist 1989). Experiments conducted with cultivation on the high marsh further support this finding (Bottema *et al*. 1980; Körber-Grohne 1967, 45-46; Van Zeist 1974, 342-343; Van Zeist *et al*. 1976).

In terms of surface area, the crop fields would surely have been modest as compared to the vast grazing grounds the marsh provided. These grazing grounds were the reason for the initial occupation of the area. Permanent settlement was possibly preceded by seasonal exploitation of the marshes in a system known

as transhumance (Van Gijn and Waterbolk 1984). Grazing and hay making are the primary uses of the Northwest European salt marshes today and in historic times and these are known to favor the development of halophytic vegetation in brackish marshes (Dijkema 1984, 1990). Dijkema (1983, 309) also points out that the construction of summer dykes leads to the disappearance of halophytic vegetation in favour of communities of the highest salt marsh, especially where agricultural use intensifies. Esselink (2000, 23–24) states that the assemblages of brackish plant species evidenced by archaeobotanical research cannot simply be accounted for by plants growing on and directly around the terp. This is confirmed by both the comparison of the terps data to the TMAP typology as well as via the phytosociological analysis. According to Esselink (2003, 24), this indicates that the terps were 'often situated in the intermediate brackish belt between the seaward stronger marine-influenced salt marshes and the freshwater-influenced inland wetlands'. A number of terps are indeed situated in this transition zone, but the vast majority of them are not. The strong representation of plants from the brackish marsh and to a lesser extent fresh anthropogenic grasslands (see Tables 5.3 and 5.4) fits well into the present salt marsh landscape in its wider sense. Brackish grassland communities of the high marsh and brackish marsh are most strongly represented in the grassland vegetation types identified.

The relatively modest role of the vegetation type *Juncetum gerardi* is noteworthy. This plant community of the middle high marsh is classically associated with the terp region (eg. Bazelmans *et al*. 2009, 27; Knol 1993, 28). Van Zeist (1974, 334) points out that a brackish subassociation, the *Juncetum gerardi eleocharitetosum*, may have been present. This would confirm Esselink's idea of widespread areas with brackish grasslands. The high frequency in which species characteristic especially of the *Juncetum gerardi leontodontetosum*, such as *Leontodon autumnalis* and *Juncus gerardii*, are found suggests that these will indeed have been more common than suggested by the present analysis, especially since these are often found in vast numbers. Nevertheless, as is the case on the present marsh, substantial areas would have been covered with *Plantaginetea majoris* grasslands, which, in

archaeobotanical literature, are surely undervalued in surface area compared to the *Juncetum gerardi*. The identification of a plant community associated with the cutting of sods fits well with the known practice of using sods as a building material for many features, such as well casings and houses. This practice must have been rather intensive during the full habitation period of the terps (Bazelmans *et al.* 2009, 64; Postma 2010).

Another sod-built feature encountered in terps is small dykes, usually interpreted as protection for crops (Bazelmans *et al.* 1999; Nieuwhof 2006a). The present study however, seems to support the suggestion that the embanked areas might also have included grassland areas (Bazelmans *et al.* 1999, 61). The height of the dykes as well as clear signs of ongoing sedimentation, indicate that the embanked plots functioned as small summer polders and not yet as permanently embanked areas (Esselink 2000, 23).

The near absence of trees in these early times confirms that no permanent embankment took place. In plant macro-remains, the most frequently identified woody species are *Erica tetralix* and *Calluna vulgaris*, which are traditionally, and most probably justly so, interpreted as originating from eroded peat layers (Cappers 1993, 177-178; Nieuwhof and Woldring 2008, 167; Van Zeist 1974, 329). They fit in well with the also frequently encountered *Sphagnum* remains. Other remains from woody species almost exclusively concern food plants, such as *Corylus avellana*, *Rubus fruticosus* and *Vaccinium oxycoccos*. The salt marsh landscape, similar to present day, would have been entirely treeless, except perhaps for the small shrub *Atriplex portulacoïdes*, the absence of which in the archaeobotanical record is probably primarily explained by the poor conservation of the characteristic diaspores, and not as Nieuwhof (2006) suggests by its actual absence.

Slightly more discussion remains with regard to trees on the terps proper, mainly fed by the study of wood or charcoal remains, generally yielding a variety of species. Casparie (1970) rules out the possibility of trees on the terp Paddepoel completely, whereas other authors suggest local growth of a variety of trees such as *Alnus glutinosa, Taxus baccata* and *Salix* (Bottema-Mac

Gillavry 2011; Out 2010b). The results of this study indicate that presence of *Alnus glutinosa* and *Salix* on the terps must have been rare. Subfossil remains of fruits and catkins of *Alnus glutinosa* are generally well-recognized in archaeobotany, whereas parts of fruit capsules and catkin bracts of *Salix* species will at least be identified on the genus level (Tomlinson 1985). The strongest argument in favor of the occurrence of trees on the terps, besides the aforementioned fruits, is the presence of leaf or bark fragments. These fragile plant parts will not have survived long-distance water transport and must thus be of local origin. Leaves of *Salix viminalis* and *S. cinerea* were identified at Heveskesklooster and Stitswerd (Beijerinck 1931, 16; Cappers 1995b, 157). Boeles mentions the occurrence of tree leaves in a dung layer at Hoogebeintum at (1951, 194). Van Giffen (1932, 29) speaks of a 'parquet floor' of *Betula* bark at Ezinge.

Given the overall preservation of plant remains in the terps, the scarce occurrence of macro-remains, leaves and bark of trees must be a true signal. The scarcity of wood is also accounted for by the find of re-used material from ships, probably drift wood, at Hallum (Bottema-Mac Gillavry 2010) and the usage of dung cakes for fuel (Nicolay 2010b; Nieuwhof and Woldring 2008). At the Halligen, planted trees occur at all terps, but they are heavily affected by the sea breeze (König 1983).

Terps within or close to the peat region between the salt marshes and the Pleistocene sands will have had trees such as *Alnus glutinosa, Salix* spp. and *Betula* spp. in their surroundings and on the terp. This area will also have been the main source area for this wood species for the inhabitants of the terps mentioned above (Bottema-Mac Gillavry 2011, 230; Hänninen *et al.* 2008).

The general picture was that of a treeless landscape, except for the terps proper, where incidental *Salix* and *Sambucus* nigra trees occurred, but in lower numbers than at the present Halligen. Evidence for fruit trees other than *S. nigra* is lacking. A recent reconstruction drawing of the former landscape, with terps dominated by trees, is probably influenced by the present-day appearance of the terps, situated behind dykes (Van Ginkel and Verhart 2009, 126–127). *Sambucus nigra* is the only frequently identified fruit tree that, given its ecology, would have been able

to do relatively well on the terps. It will also have been able to spread more easily from terp to terp, as it is primarily endozoochorically dispersed by birds, unlike trees such as *Corylus avellana* and *Quercus robur*. The drinking ponds on the terps ('dobbes') provided a logical resting place for the birds on the terps.

A small *Sambucus nigra* specimen is presently growing on the water edge of one of the embanked ponds on the Frisian Noarderleech salt marsh. Similar brackish water ponds were present in the terp region, although in the past they were located on the terp proper. These ponds formed a unique isolated brackish aquatic ecotope in an area where most of the creeks and ditches must have maintained relatively high salinity values throughout the year. Several studies describe the vegetation in such present ponds (Claassen 1983; Jager and Rintjema 2011; Joenje 1975; Verhoeven *et al*. 1978). The combined species list of these studies is remarkably similar to the list of aquatic and semi-aquatic species identified in the archaeobotanical samples. Besides the brackish species in category A of the TMAP Typology, this includes taxa such as *Hippuris* vulgaris, Ranunculus subg. Batrachium and Lemna. Especially these species were probably confined to the ponds, which means at least some of these can be assigned to category 4 from Verhoeven *et al*. (1978), with salinity values between 1.8 and 3.0 ‰ Cl-. The rather frequent occurrence of marsh plants such as *Mentha aquatica, Typha* and *Schoenoplectus tabernaemontani* suggests that even more fresh conditions will occasionally have occurred in ponds on the terps. In the transition zone between the salt marshes and the inland wetlands, these species will have been part of the 'normal' aquatic and riparian vegetation.

Comparison to the present situation and implications for nature conservation | The effect of human impact on the salt marsh in recent and historic times has long been acknowledged and studied extensively within an ecological context (Adam 1990, 356–375; Bakker 1983, 1989; Beeftink *et al*. 1978; Dijkema 1983). Bakker (1989, 80) and Esselink (2000, 24) state that the marshes were exploited intensively, pointing out the relatively few finds of *Elytrigia atherica, Atriplex portulacoïdes* and *Artemisia maritima*, spe-

cies characteristic for ungrazed marshes. Nieuwhof (2006a, 132) objects to their line of reasoning, pointing out the limitations of archaeobotanical data. According to Nieuwhof, the absence of a certain species in a certain region can only become meaningful when it is generally well-recognized in archaeobotany. The present analysis shows that *Elytrigia atherica* is identified frequently enough to meet this criterion (see Table 5.3). Based on low numbers in the pollen record, Woldring and Kleine (2008, 265) conclude that the abundance of *Artemisia maritima* must indeed have been low. For this species and *Atriplex portulacoïdes,* the poor preservation of the fruits do not legitimate any conclusions regarding its past abundance. On the basis of the pollen record however, and the scarce but convincing presence of *Elytrigia atherica,* the conclusion is justified that the marshes were under influence of grazing for most of the region from the Iron Age onwards. A final remark to be made in this respect is that recent research shows that *Elytrigia atherica* communities are not always the final stage in salt marsh vegetation, but can, without grazing, be succeeded by stands of *Phragmites australis* and *Juncus gerardii* (Veeneklaas *et al*. 2013).

Much more than grazing took place on the marshes in the past however. People were living on the marsh, not just to allow for grazing their livestock. A practice not or hardly studied at all, is the effect of traditional crop cultivation on vegetation in a salt marsh area, although many studies and experiments focus on the potential of the salt marsh for growing crops (Brul 2012; Glenn *et al*. 1999). Dijkema (1983, 321) already points out that agricultural practices can have a positive effect on the vegetation diversity in the summer polders. An experiment with traditional farming on small plots, will undoubtedly result in a arable weed community lacking a present-day analogue, thus contributing to biodiversity on the community rather than the species level. Further differences in the appearance of the landscape will have been caused by the geomorphology. Grassland communities such as *Juncetum gerardii* grasslands are rare on the Dutch mainland now, because the necessary permanently moist floodplains are lacking (Schaminée *et al*. 2010, 282). The cutting of sods, currently confined to the Wadden Sea Islands,

had a big influence on the vegetation in the past. This practice is strongly related to these types of grassland (Bakker *et al.* 2009). However, *Ranunculus sardous* and *Carex otrubae,* known to occur in saline grasslands, only occur in about 2% of the present *Juncetum gerardii leontodontetosum* plots (Hennekens *et al.* 2010). The presence of a non-analogue *Juncetum gerardii* type grassland in the past is therefore likely.

The salt marshes in the prehistoric and early historic past show great resemblance to the present marshes on the species level, as shown by the TMAP analysis. The present Dutch mainland salt marsh is defined as a semi-natural landscape, whereby the difference with natural landscapes is primarily defined by the naturalness of the marsh drainage (Bakker 2012; Bakker *et al.* 2005). The older marshes were possibly even more anthropogenically influenced, especially in the direct surroundings of the terps. Schaminée *et al.* (1996, 35-37) suggest that the *Ranunculo-alopecuretum geniculati* can locally be labeled as potential natural vegetation, being the result of grazing by wild large herbivores. Archaeobotanical research in the terp region can be used to assess long term human influence. Identifying undisturbed natural vegetation is not possible, for all data point to a landscape heavily exploited.

FUTURE RESEARCH | The present study shows that variation in the vegetation in the former salt marsh area is not related to differences in the period under study, except for a number of SG's from period 4. This is probably caused by the fact that these do in fact belong to a period when permanent endikement had happened locally. The wide dates provided for these SG's prevented their exclusion from this research at an earlier stage. Although the Frisian terps appear to be more similar to each other, too little data is present from the Groningen area as yet. To strengthen this interpretation, more research is necessary in this region. Another understudied area is the transition zone between the salt marshes, the peat region and the Pleistocene sand. More study here would greatly enhance the understanding of a zone absent in the present-day landscape. In this study, but also previously, it is shown that the degree of diversity and human influ-

ence in the landscape facilitated local crop cultivation. Recent, yet unpublished, research indicates that this probably included more crop species than previously assumed and that there might have been variation at this point within the terp region. A further analysis of these crop plants will also extend the knowledge on past salt marsh weed vegetation and crop husbandry practices. Finally, the analysis of the archaeobotanical data is severely hampered by the fact that most sampling is carried out within a settlement context. Studies such as performed by Kuijper (2008) and Schepers (2012a), dealing with samples from natural creeks, testify of pre-habitation salt marsh vegetation lacking the typical settlement noise. More analyses of samples from natural creeks or channels further away from the terp proper or predating local habitation is necessary to understand the less-disturbed parts of the past landscape.

Notes

1 This is a simplification of the many different terms encountered. Apart from ditch, words such as gully, trench and creek occur. Wells also includes 'dobbes' and water pits. The different terms seem to both reflect real differences (e.g. natural creeks versus man made ditches) as well as differences between the different groups or even individuals describing the context.

2 This number is set on 74 and not 75 because Zostera is present both on the genus and the species level (Z. marina and Z. noltii) and might otherwise incorrectly be represented by three taxa.

General discussion

In this dissertation, I critically evaluate approaches commonly used in archaeobotany and palaeobotany for reconstructing vegetation, and I strive to make some improvements to these approaches. Moreover, I emphasize the vital role played by a good understanding of taphonomy and site formation in the interpretation of past ecology. However classic this theme may be, it has not lost in significance (see, for example Butzer, 1982, 177-184; Cappers and Neef 2012, 173-198; Lowe and Walker 1997, 162-163). The Dutch National Archaeological Research Agenda (NOaA, Brinkkemper *et al.* 2005, 5) points out that archaeobotanical research conducted in the past was very much focused on 'botanical and phytosociological data', but that more recently, a shift can be witnessed toward an interpretation of the data from a human perspective (my translation). In that sense, the present study is rather traditional, taking the natural and synanthropic vegetation in a region as a starting point, rather than being a tool for understanding cultural phenomena. However, in my view, vegetation was part of the life and environment of past people

and therefore very much relevant. This is therefore both a pal-aeobotanical and an archaeobotanical study, whereby palaeo-botany is believed to focus on 'natural' flora and vegetation and archaeobotany, on human plant use and synanthropic vegeta-tion. However, it has been broadly acknowledged and frequently shown that the possible modes of human impact on landscape and vegetation are numerous, and that they stretch far beyond such evidently anthropogenic landscape entities as settlements and cereal fields (Delcourt 1987; Sukopp 1969). As was also ac-knowledged by Brinkkemper *et al.* (2005, 23), the distinction be-tween the natural landscape and the cultural landscape is rather artificial in environments where human presence is undisputed. Although it is primarily used for salt marshes, it is interesting to adopt this distinction between a natural and a semi-natural landscape for both types of environment under study here (Bak-ker 2012; Esselink *et al.* 2009). This 'degree of anthropogeneity' is of the utmost relevance to archaeology.

In this concluding chapter, I will evaluate to what extent the primary goals of this study have been achieved. Two main research questions were formulated. The dominant research question was: *Is it possible to improve the reconstruction of past veg-etation at the most detailed level?* The second question, follow-ing from the first one, was: *Does a more detailed reconstruction of vegetation enable us to expand our understanding of past human interaction with the landscape?* I will first address the (affirma-tive) answers that can be given to both questions. Next, I will discuss some possible methodological and theoretical points of debate. Finally, I will address the future prospects of the study of past vegetation.

IMPROVED VEGETATION RECONSTRUCTION | The combinations of co-occurrence of multiple taxa are used for a new technique (Chapter 2 [Schepers *et al.* 2013b]). A phytosociological approach to the reconstruction of past vegetation based on present-day co-occurrence values of plant taxa is presented. Because the method makes use of overlapping species groups, it does not restrict spe-cies with a broad ecological range to only one vegetation type. In this way, a reconstruction of a landscape can be made for envi-

ronments in which different types of vegetation occur in a more natural gradient. The method is especially suited to the analysis of archaeobotanical assemblages representing a variety of vegetation types.

A remark by Kroll (1975, 51) regarding his research on the German island of Sylt is of particular relevance in this respect: 'Eine differenziert qualitative Vegetationsrekonstruktion […] ist kaum möglich. Es fehlen *"reine Proben"* mit pflanzichen Resten nur eines Vegetations-Typs.' Although this statement dates back almost four decades, the idea that pure samples (reine Proben) are of the utmost importance for vegetation reconstruction is still widely accepted. Even today, these types of samples are the only ones that allow for the identification of a vegetation type that lacks a modern analogue.

In Box 1, an example of such a pure sample is studied in detail. The sample is a compact buckwheat concentration, including associated arable weeds. The phytosociological method as presented in Chapter 2 (Schepers *et al.* 2013b) does identify arable weed communities for this sample, but some problems occur. An important disadvantage of focussing on pure samples is the fact that only a very limited number of vegetation types can be expected to be represented in uncontaminated form. Besides arable weed communities, believed to be represented by crop concentration finds (as shown in Box 1), these are grassland communities, potentially identifiable through hay samples (Körber-Grohne 1967). Pure hay samples are extremely rare. Vegetation types that are neither directly related to cultural behaviour nor part of a hydrosere (and therefore preserved in peat deposits) will seldom be encountered as a pure sample. Willow carrs, heathlands, and settlement vegetation are examples of vegetation types whose remains will not occur in a pure sample.

Palaeoassocia does not require pure samples for a complete and detailed vegetation reconstruction. For the Swifterbant river system, the method proved to work exceptionally well (Chapter 3 [Schepers 2014]). Not only could a high number of different vegetation types be identified, but the combination of taxa from settlement layers resulted in the identification of relatively more ruderal and arable weed communities because of

the combination of taxa in samples from that context. This is an important finding, because even generalist species can, by their specific combination, now contribute to a more detailed vegetation reconstruction.

From a vegetation point of view, it was observed that a limited number of (species-rich) samples from a drift line proved sufficient for an exceptionally complete reconstruction of the vegetation types that must have been present in the area in the past (Chapter 2 [Schepers *et al.* 2013b]). This concept is explored further in Box 2. Creeks and ditches are among the most commonly sampled feature types in archaeology. The finding that these very mixed assemblages are undervalued in archaeobotany is here expanded on to claim that they form an excellent sampling context from which to gain insight into vegetation in areas farther away from or between settlements.

Another type of context found in wetland areas that is frequently studied in archaeobotany is dung deposits. The relationship between standing vegetation from a known hay field and the botanical composition of cattle and sheep dung is dealt with in Chapter 4. An important finding from this study is that macro-remains from both cattle and sheep dung well represent the grassland vegetation in the hay field at the presence/absence level, and that pollen from this dung adequately mirror the surrounding vegetation.

This finding is especially relevant for chapter 5 (Schepers *et al.* 2013a), where a review is presented of past salt marsh vegetation in the terps area. In this chapter, a large number of samples resulting from 40 years of research is subjected to multiple types of analysis (see below). An important finding is that the classic description of plant remains from a salt marsh area, which takes the halosere as a starting point, while not necessarily wrong, pays insufficient attention to the fact that the most intensely exploited parts of the landscape, those parts directly surrounding the terps, lie for a great part outside of the range of this zonation. Dung samples are frequently retrieved in the terps area. These are often found to be a mixture of dung and other material. The combined observation that dung from hay represents the source grasslands very well and that mixed as-

semblages are not necessarily problematic allows for a highly detailed vegetation reconstruction in the area.

MAJOR IMPLICATIONS FOR THE SWIFTERBANT RIVER SYSTEM AND THE TERPS AREA | This study takes the reconstruction of the vegetation in the Swifterbant river system and the terps area as a starting point for addressing human behaviour. Human behaviour can only be fully understood when all archaeological data are combined, both cultural and ecological. This study does not aspire to fully solve major archaeological issues in the areas merely by studying vegetation. That being said, the main findings for both areas from the previous chapters will be summarized here, complemented with some noteworthy observations that occurred to me during the course of this research.

Human impact on the landscape | In both the Swifterbant and the terp region, clear signs of human influence on the landscape exist. At Swifterbant S3, there are indications that people raised the ground surface level in the settlement through the intentional deposition of reed bundles (Van der Waals 1977, 18). Initially, the overall impact on the landscape appeared hard to detect in pollen diagrams, but new research in the adjacent Noordoostpolder is yielding remarkably positive results, providing indications for both grazing and cereal cultivation (Out 2009a, 178; Weijdema *et al.* 2011). The results of the Palaeoassocia analysis for the Swifterbant area indicate that the scale of these activities must have been modest, perhaps even restricted to the direct surroundings of the settlements (Chapter 3 [Schepers 2014]). This is partly in accordance with the findings of Ten Anscher for the Noordoostpolder, although he does mention indications for intentional burning of vegetation as a larger possible mode of impact on the local vegetation (2012, 533). The analysis of samples from drift lines directly adjacent to the prehistoric settlements led to the identification of vegetation types typically associated with the dynamics of natural river system environments. This vegetation would be defined as a semi-natural landscape – including livestock grazing and mowing – in the categorization for the salt marshes (Bakker 2012, 250). More profound

modification of the landscape would be necessary to reach the next stage in his division of landscape types.

Such is the case for the terp region. Not only the terps themselves, but also both the archaeobotanical and archaeological results, testify to a landscape profoundly influenced, even formed, by human activity (Chapter 5 [Schepers *et al.* 2013a]). The density of ditches in the direct vicinity of the terps is already an indication of active management of the marsh drainage (Nicolay in prep.). Modern infrastructure projects cutting through the former salt marsh landscape in the terp region have revealed that these ditches were not restricted to the direct surroundings of the terps (Lenting and Van Malssen 2009). Small summer dykes are another clear example of landscape management (Bazelmans *et al.* 1999).

Cereal cultivation in the study areas | Both study areas are the subject of an ongoing discussion on whether or not local cereal cultivation was being practiced (Cappers and Raemaekers 2008; Out 2008, 2009b; Van Zeist *et al.* 1976). Remarkably, recent reviews of wetland archaeology in general (Lillie and Ellis 2007; Menotti 2012) pay little or no attention to cultivation in wetlands. I suspect this lack of attention is the result of the fact that for many wetland sites, higher, drier ground is not that far away. This drier ground is generally said to be the location for cereal cultivation. The implication seems to be that cereal cultivation was not practiced in the wetlands.

The question of local cultivation was answered with the discovery of plough soils in clear wetland situations in both study areas. Moreover, the vegetation analysis for both study areas clearly points to the existence of arable weed communities (Chapters 3 [Schepers 2014] and 5 [Schepers *et al.* 2013a]). It should be noted here that archaeological plough layers were identified in the German salt marsh area decades ago (Körber-Grohne 1967; Behre 1976).

Subsequent to the discovery of plough-disturbed soils in the Dutch wetlands, the discussion shifted from whether local cereal cultivation was possible in the first place to what crops might have been cultivated, where exactly, and on what scale

(Huisman *et al.* 2009; Van der Laan 2013a). Many data have been collected in recent years, especially from the terp region, but also from the Swifterbant area (and additional data are still being collected). Although these data are not yet published, some remarkable results should be mentioned here.

Two cereals occur both in the Swifterbant area and in the terp region, namely, six-row barley *(Hordeum vulgare* subsp. *vulgare)* and Emmer wheat *(Triticum turgidum* subsp. *dicoccon)*. Experiments in the unprotected salt marsh have shown that barley copes better with the environmental constraints of that landscape than do wheat species (Van Zeist *et al.* 1976; Bottema *et al.* 1980). Brinkkemper and Van Haaster (2010) did indeed find a correlation between site salinity and the ratio of barley to wheat. In both the Swifterbant and the terp region, barley is by far the dominant cereal, indicating that not just salinity but also moisture must play a role here. The water in the Swifterbant area has been found to be at most slightly brackish, but primarily fresh. The ratio of barley to wheat has therefore also been suggested as a possible argument for local cultivation by Out (2008, 135).

The most recent archaeobotanical overview of crop diversity in the northern Netherlands was presented by Cappers *et al.* (2005). Their presence/absence data per period show that hulled barley is constantly present, whereas Emmer (*T. turgidum* subsp. *dicoccon*) and Bread wheat (*T. aestivum* subsp. *aestivum*) are rare. Moreover, Bread wheat appears to be absent from the terp region before the Middle Ages, when it is found, for example, at Beetgumermolen (25)[1] and Wijnaldum (16) (Van Haaster 2005; Pals 1999). This is remarkable, given the fact that numerous finds of Bread wheat are known from other parts of the Netherlands at an earlier date, especially from the Iron Age onwards (data from RADAR, version 2006, Van Haaster and Brinkkemper 1995).

The study of more sieve residues from terp sites over the past few years did not result in any finds of Bread wheat either. Rather unexpectedly, however, another hexaploid wheat subspecies was identified. Found only once previously in the terp region, in a sample from Leeuwarden (9) dated to around 1000 AD (Van Zeist *et al.* 1987), Spelt wheat (*Triticum aestivum* subsp. *spelta*) was identified from an Early Roman sample from the terp site of

Jelsum (Hondelink 2012). Remains of this crop were also found in Oosterbeintum, but these could not be dated very accurately.

Discussing the terp of Wijnaldum (1999), Pals mentions that there is only one other record of Emmer wheat (*T. turgidum* subsp. *dicoccon*), namely, from Paddepoel (3) (Van Zeist 1974). Indeed, Emmer wheat has long been extremely rare in the archaeobotanical record of the terp sites, even on the presence/absence level. Noteworthy in this respect is the site of Heveskesklooster (13), where, in contrast to some of the other sites, the absence of Emmer wheat is not likely to be the result of an insufficient number of studied samples (Cappers 1995b).

The number of records of Emmer wheat has increased markedly since 1999 (table 6.1). The previously mentioned experiment with cultivation on the salt marsh showed that all wheat taxa performed poorly in comparison with barley (Van Zeist *et al*. 1976; Bottema *et al*. 1980). The low numbers in which Emmer wheat is generally found led Behre to suggest that it may have been an unintentional admixture to barley at Elisenhof (1976). This explanation was rejected by Van Zeist at Middelstum, who noted that the percentage of wheat was too high to sustain this assumption (1989). If it is not an unintentional admixture, another explanation may be that wheat was imported from the sandy soils south of the terp region. This is deemed unlikely by Van Zeist (1989, 115) because 'no arable weeds characteristic of sandy soils' were found. This line of reasoning was later followed by Nieuwhof for Peins-Oost (2012, 75). It has to be concluded, however, that Emmer wheat was cultivated in the terp area as well.

	Site name	Reference	Period
24	Friesestraatweg	Cappers *et al.* 2005	2
26	Sneek Stinswier	Hänninen and Van Waijen 2005	4
33	Goutum	Out and Kaaijk 2010	1
34	Peins-Oost	Nieuwhof 2012	2
35	Marssum	Verbruggen 2012	2
36	Achlum	Schepers in prep.	1
37	Arkum	Maurer 2013	2

38	Jelsum	Hondelink 2012	2
-	Sneek Akkerwinde	Schepers 2012b	3
-	Oosterbeintum	Unpublished data	1 / 2 / 4
-	Firdgum	Unpublished data	3

Table 6.1 Recent (post-2000) finds of Emmer wheat in the terp region. For an explanation of the table, see the caption to Table 5.1, and for the location of the sites, see Figure 5.1. Sites without a number are not included in that chapter

A final crop to be mentioned here is Rye *(Secale cereale)*. Rye is adapted to sandy soils and rarely found in the terp region. Until recently, all known finds from the region were dated after 1000 AD, with the exception of one imprecisely dated find in Baflo (18) (De Roller and Korf 2002). Recently, a number of Rye kernels were found at the terp sites of Firdgum and Oosterbeintum, dated to both the Roman Period and the Early Middle Ages. The fact that the terp site of Firdgum is located on an usually sandy salt marsh ridge may very well explain why this species turned up here. It was probably cultivated on the ridge proper.

Evidently, a synthesis on crop plants in the terp region is currently lacking. A systematic summary of available evidence from various sources, as presented for marginal Neolithic wetland sites by Out (2008), would be useful. New excavations carried out in the area over the past few years, and several more to come, will also allow for a better understanding of variation within the area.

Both in the Swifterbant area and in the terp region, stable isotopes seem promising for studying the possible importation of some of the cereals, especially Emmer wheat. Given the recent finds, however, it is my impression that barley was undoubtedly dominant, but that other cereals were occasionally cultivated as well – and in many years successfully. Especially for the terp region, future research will have to tell whether or not there were any differences within the region. Imports of cereals were probably rare, and supposedly primarily relevant to the terp sites relatively near to the sandy soils.

Grazing and hay making | The Swifterbant creek system and the terp region represent profoundly different landscapes. In the veg-

etation analysis, this is primarily illustrated by the more modest role of grasslands in the Swifterbant area and the absence of woodland vegetation in the terp region. The Early Neolithic people of the Swifterbant Culture raised domesticated animals, but hunting and fowling still played a big role in their subsistence (Raemaekers 1999; Zeiler 1999). Coprophilous fungi in the pollen diagrams further point to grazing on the river banks (Van der Veen 2008).

In the terp region, the grasslands were probably the primary reason for the colonization of the region (Van Gijn and Waterbolk 1984). The few finds of *Elytrigia atherica,* in particular, point to a heavily exploited landscape (Bakker 1989, 80). It should be kept in mind, however, that signals of the areas of the salt marsh that were not used are also less likely to be found in a terp settlement context. The dung layers in the terps most likely represent stable manure, which means they are a mixture of animal dung and straw or hay (see also Körber-Grohne [1967, 73]). The animals were fed with hay, indicating that at least parts of the grasslands surrounding the terp were probably kept free of grazing during summer (Chapter 5 [Schepers *et al.* 2013a]). My analyses of some of these remains seem to confirm that hay was being used as feed. High numbers of full-grown *Rumex crispus* fruits (including perianth) were encountered in samples from Achlum (Schepers in prep.). Free-ranging animals generally tend to avoid this species once it has reached its fruiting stage, but they cannot make this selection when being fed with hay.

There are recent indications that the salt marsh grasslands were further managed by intentionally burning last year's vegetation, as discussed by Exaltus and Kortekaas (2008). Numerous finely laminated charcoal layers are found within organic clay sediments. How exactly the findings of Exaltus and Kortekaas should be interpreted, and under what circumstance this burning occurred, is as yet unclear. Groenendijk (2008, 79), citing Exaltus and Kortekaas, describes how two so-called vegetation levels in the clay deposits that have long been known about were found to consist not of decomposed plant remains, but of burned material. Huis in 't Veld (2010) describes these layers as being a mixture of decomposed plant remains and burned

material. This seems to make sense, since something needs to be burned, and the local preservation conditions would allow for the recovery of waterlogged remains. In the same volume, however, Vrede *et al.* (2010) state again that the dark colour of the 'vegetation levels' is caused entirely by burning. Vrede *et al.* found many, but also almost exclusively, fruits of *Eupatorium cannabinum* in the layers. This would indicate that the burning did not take place in a salt marsh environment. The botanical analysis of vegetation horizons by Bohncke (1984) seems to confirm this. His samples are very different from the other samples from the terp area and also very different from the present-day salt marsh (Chapter 5 [Schepers *et al.* 2013a]). Recently, Aalbersberg and Huisman (in prep.) convincingly argued that comparable layers in the vicinity of Leeuwarden are present in deposits that must have been too wet for grazing for most of the year.

In my view, obtaining a definitive answer would require palynological analysis on these layers. If they are, indeed, exclusively made up of burned material, this will not work, for hardly any pollen will survive burning. However, it seems unlikely that no unburned organic material will be preserved at all.

Vegetation in time and space | The Swifterbant area allows for a very detailed landscape reconstruction. The geomorphology of the creek system is exceptionally well preserved, and excellent maps are available (Dresscher and Raemaekers 2010). This allows for a good reconstruction of the spatial distribution of the identified vegetation types. Because much of the back swamp has, unfortunately, eroded over time, the situation in these parts of the landscape is less clear. The Swifterbant landscape is made up of a river system, with a mire in the hinterland. From a very Dutch perspective, it would probably be best described as a cross between two national parks: De Biesbosch (a freshwater tidal system in the south-eastern part of the country with willow, wet grasslands, and reeds) and De Weerribben (a mire area in the north-western part of the country). Especially in the field of palynology, the vegetation development in an area is frequently described in terms of the known succession in a hydrosere. However, part of the reason that the hydrosere is so

well understood is that it can also directly be viewed in zonation. In the Swifterbant environment, multiple hydrosere plant communities will have existed simultaneously. Palynological results from a single core, or from a low number of cores, can therefore be very useful for the reconstruction of long-term developments, but should be used with caution when describing a succession of plant communities.

Great improvements have been made in our knowledge of the geomorphology and geology of the former terp region through the work of Vos (e.g. Vos 1999; Vos and Knol 2005). In my view, it would be highly desirable to combine parts of Vos's maps with more detailed visualization of vegetation. Assessing long-term human impact in environments as dynamic as the terp region is complicated. Geological and geomorphological changes – as well as possibly, but not necessarily, related climatic changes – will also affect the vegetation. However, substantial climatic changes are likely to affect the whole region; they thus partly explain major cultural phenomena. Changing natural conditions may have played a role in the Migration Period in the terp region (4th and 5th century AD; Nieuwhof 2013). Interestingly, a Mann Whitney U test performed on the 'fresh' values (indicator value for low salinity) as calculated for the samples from the four different terp habitation periods (Chapter 5 [Schepers *et al.* 2013a]), shows that the Roman era (period 2) was not only significantly fresher than the preceding Iron Age, but also significantly fresher than the Early Middle Ages. The much more accurately dated samples that are now available may serve to strengthen this very preliminary finding in the future.

METHODOLOGICAL DISCUSSION | Why macro-remains are best suited for high-resolution vegetation reconstruction | Throughout this study, plant macro-remains are used to reconstruct vegetation and to understand the relationship that existed between humans and this vegetation in the past. Primary, non-macro-remain data are only presented in chapter 4 where it concerns pollen. Data from other proxies are presented in both Chapter 3 (Schepers 2014) and Chapter 5 (Schepers *et al.* 2013a). These are all from secondary sources, although they do include data

from previously undisclosed reports, such as the diatom reports from the Swifterbant area (De Wolf and Cleveringa 2005, 2006, 2009a, 2009b). Because no new data from other proxies are presented, the present study would probably have to be defined as adopting a predominantly mono-proxy approach. Multi-proxy approaches have become increasingly common for the reconstruction of past climate and environments, but they were, in fact, being adopted long before the term became fashionable (as pointed out by Birks and Birks [2006] as well as Lotter [2005]).

The strong focus on plant macro-remains in this study is directly related to the primary goal: the detailed reconstruction of the vegetation. Naturally, a number of other proxies are directly or indirectly 'botanical' and therefore relevant to vegetation reconstruction. Pollen and wood (including wood charcoal) are the most important ones for a reconstruction of natural/undisturbed vegetation (Brinkkemper *et al.* 2005, 23).[2] The potential of some other relevant proxies will also be addressed.

The fact that pollen taphonomy in a dynamic coastal environment is highly complicated explains why very little pollen analysis has been carried out on natural deposits in the clay area of the present provinces of Friesland and Groningen. Those palynological analyses that have been carried out do not relate, or only obliquely relate, to archaeology (Bohncke 1984; Roeleveld 1974). Moreover, the fact that much of the pollen cannot be identified to the species level hampers detailed vegetation reconstruction. For example, Chenopodiaceae-type pollen is generally well presented in salt marsh environments. This can be explained by the very high proportion of halophyte species within that family (Cleveringa 1978; Glenn and Brown 1999). These pollen create difficulties because they represent species from both different salt marsh zones and settlement-related ruderals. Research in northern Germany also indicates that pollen analysis in a salt marsh environment is complicated, and of limited additional value to the analysis of plant macro-remains (Behre 1976, 57–59).

Wood (including charcoal) is an important additional source of information for wetland environments. Although many taxa can only be identified to the genus level, in historic and prehistoric context it is often possible to deduce the species

concerned. In addition to yielding a list of taxa, wood remains may also be used to judge upon the possible age of the woodland and any human impact on woodland vegetation (e.g. Casparie *et al.* 1977; Out 2009, 178; Out *et al.* 2013;). Wood studies have therefore been used as a supplementary source in the Swifterbant area, where local occurrence of trees is undisputed (Chapter 3 [Schepers 2014]). The discussion is somewhat different when a former region was virtually treeless and most wood remains are believed to have been brought in culturally or are interpreted as driftwood. Although this is the case for most of the terp region (Chapter 5 [Schepers *et al.* 2013a]), little is known about the transitional peat zone. I believe, that the excellent master's thesis by Van der Laan (2013b) emphasizes that the extensive study of wood remains from terps in this area is required, and that this will improve our understanding of the local vegetation.

A proxy that has received increasing attention in archaeology over the past few years is stable isotope composition. Stable isotopes can also be used to differentiate between a coastal and a terrestrial signal (West 2013). In coastal environments, higher $\delta15N$ values, in particular, are used to distinguish between a marine and a more terrestrial signal (Britton *et al.* 2008; McManus *et al.* 2013; Nieuwhof 2008b; Smits and Van der Plicht 2009). In the geographical areas covered by the present study, stable isotopes will help in identifying possible imports of animals, crops, or people. Furthermore, they may serve to differentiate between different grazing areas for some of the livestock (Prummel and Van Gent 2010). For the reconstruction of the natural vegetation, however, they are of little added value.

Phytolith analysis is a promising technique for the study of contexts where organic plant parts are not or poorly preserved and is therefore not commonly used in wetlands. However, contexts with poor preservation are also present in wetlands. These include ash layers (Braadbaart *et al.* 2012) and prehistoric plough soils. Given its function, the plough soil will, in most cases, not have been permanently waterlogged and hence will lack ideal preservation conditions for seeds. Therefore, the arable weed vegetation will have to be reconstructed by other means (Robinson 1992, 203; see also Box 1 and Box 2). That poor preservation

conditions in field layers are not a given is illustrated by the excellent preservation of plant macro-remains in the Swifterbant arable field layers[3] and by a recent analysis from field layers at the terp site of Jelsum (Van der Laan 2013a).

Chemical analysis on plant macro-remains from Dutch wetland sites, though useful to resolve preservation issues, was found not to be a viable method for species identification (Van den Berg *et al.* 2010). However, as emphasized in Chapter 5 (Schepers *et al.* 2013a), the classic assumption that wetlands sites are a guarantee for good preservation conditions has to be challenged. My personal observations on plant macro-remains indicate that these preservation conditions do not equally affect all ecological taxon groups of plant families, a point that was previously made by Behre[4] and Cappers (1994). In less well-preserved sediments, the relatively fragile remains of Poaceae species, which are so essential for the reconstruction of grassland environments, will rarely survive. Most Polygonaceae species, however, which are well represented in settlement or arable weed vegetation, are generally 'the last seeds standing' under these conditions. Another family that should be mentioned in this context is the Juncaceae. The seeds of species within the eponymous genus *Juncus*, in particular, can be preserved under less favourable conditions. Furthermore, *Juncus* species produce vast numbers of seeds. These differences will have to be taken into consideration when different sites are compared.

DNA analysis (for a review, see Schlumbaum *et al.* 2008) may lead to the identification of botanical remains to a lower taxonomic level than is possible with most proxies mentioned above. However, even when DNA analysis leads to the identification of species or subspecies never identified before, vegetation reconstruction would still require an assessment of the inter-specific relationships among the identified taxa. Nonetheless, promising studies on fish DNA in water are being conducted in ecology that may prove applicable in palaeoecology in the future (Dejean *et al.* 2011).

A final proxy that should be mentioned here is geology. Extensive geological (and geomorphological) analysis has been performed in both study areas. A combination of geological and

palaeobotanical data can be used to reconstruct the landscape, including vegetation (e.g. Gotjé 1993; Van Dinter 2013). However, a broad division of a salt marsh landscape into vegetation zones based on the surface level in relation to the mean high water level at a certain point in time alone should not be considered a 'vegetation reconstruction'. Especially in the higher parts of the marsh, too many other factors, such as grazing pressure and drainage quality, highly influence the vegetation composition (Bakker 1989; Behre 1985; Esselink *et al.* 2009).

The primary advantage that plant macro-remains have over most other proxies, such as pollen, is that they can often be identified to a lower taxonomic level (Lowe and Walker 1997, 185). For the reconstruction of vegetation and food economies at the most detailed level, this is a prerequisite. Nonetheless, for research focusing on long-term changes or development in the environment, multiple proxies will surely have a complementary effect.

How to make seed counts count | Most analyses and interpretations in this study are performed using presence/absence-data. This is due in no small part to the fact that many of the published studies do not sufficiently describe the methodology or made sample selection choices that are likely to favour some (groups of) species. Moreover, the relationship between seed counts and vegetation is complicated (Cappers 1995a; Dieffenbacher-Krall 2007).

Nevertheless, even in mixed assemblages, plant diaspores tend to retain some clustering (Chapter 4). Seed counts can be used in addition to qualitative examination of plant remains if a substantial number of samples resulting from a thoroughly thought-out sampling procedure are studied. So far, such studies and analyses have been mainly focused on food plants and associated arable weeds (Maier and Harwath 2011; Van Zeist and Palfenier-Vegter 1981). Similar comparisons could be made if we increased our understanding of the relationship between standing vegetation and sample composition. As pointed out in Box 2, the fill of ditches outside of a settlement context may provide information on wild vegetation in off-site areas. Both human-made and natural creeks and ditches were rarely encountered by archaeologists in the past, since most excavations focus on

settlements. Recent large-scale infrastructural works bring new possibilities in this respect. What is currently lacking is an overview of the relationship between the macrobotanical content of ditches and the various vegetation types. Ecological studies of this relationship do not face the same problems and do not ask the same questions as archaeological studies do. Therefore, their sampling methods render a direct comparison with archaeobotanical data problematic. In my view, a standardized ecological study of the fill of these ditches in a variety of ecosystems, whereby sampling is carried out in a way that is comparable to archaeological sampling, would be very useful.

New field work on Dutch terp sites allows for new sampling strategies. The tradition of primarily sampling 'organic fill', such as dung layers and wells, has been abandoned in line with Kooistra's recommendation to sample different types of features (2002b). Moreover, the sample volume was reduced to about 1 litre, as opposed to the 5 litres recommended by Kooistra (2002b), but in line with the strategy recommended for similar conditions by Maier and Harwath (2011). If the material is indeed well preserved, this volume is sufficient for studying vegetation in wetland environments. If not, a higher volume will not make much of a difference. A standardized sample volume, if so desired complemented with residue volumes, will allow for a useful quantitative analysis.

Flotation samples in wetland sites | At some sites, the lab-processed samples are complemented by large-volume (12–24 litre) samples that are water-sieved in the field on a mesh width of 2 mm, after which the plant remains (both charred and waterlogged) are recovered through flotation. These remains are of particular interest for information on economic plants. Because sieving in the field is generally carried out with ditch water, the possibility of contamination with recent material should be taken into account. However, to exclude all non-waterlogged remains in this situation would be to exaggerate this risk. The combination of the large-volume field samples with laboratory samples is common in prehistoric excavations (e.g. Bakels *et al*. 2001; Van Zeist and Palfenier-Vegter 1981), but in the terp region this approach

has so far been applied only at Wijnaldum (Pals 1999). Drying out waterlogged plant remains will affect the results (Tolar *et al.* 2010), and the data should therefore always be accompanied by those from wet samples. Recent studies on material from some of the terp sites, however, also show that flotation samples alone allow for both a good 'characterization'[5] of the vegetation and the study of long-term changes (Hondelink 2012; Maurer 2010).

Choice of type of analysis | There is a paragraph on 'new techniques' in the NOaA chapter on archaeobotany (Brinkkemper *et al.* 2005, 22). This paragraph explicitly seeks innovation in producing more (types of) data, through new proxies (see above). In Figure 1.5, this primarily concerns stage 4, but also a stage in between stages 4 and 5, where techniques such as DNA and stable isotope analysis would fit. The present study, however, explicitly seeks to introduce innovation in stage 5 of Figure 1.5: the analysis of the data once these have already been established.

As illustrated in Figure 1.1, there are several pathways to get from an archaeobotanical sample to vegetation. Different approaches have been used throughout this study. It is of the utmost importance to stress that none of these was found to be 'the best'; the approach should be decided upon for each study individually. Moreover, different approaches can be combined in one study (Box 1).

The level of landscape and vegetation reconstruction that is being aimed for will primarily determine the kind of analysis. If it the aim is to obtain a 'characterization' of vegetation rather than a detailed reconstruction, it may not be required to define assemblages *at all*. Such a characterization is particularly relevant when comparing between sites or periods.

Selected species, the so-called indicator species, can serve to address specific issues based on a strongly reduced, simplified version of the total dataset. Behre (1985, 1991) proposed a set of sixteen halophyte and sixteen glycophyte species to define a salinity ratio, a method later refined by Brinkkemper (1993, 102) and Cappers (1994). Brinkkemper and Van Haaster (2010) convincingly showed the interrelationship between this salinity ratio and the presence of different cereal taxa. Although a much

longer list of species is used, the TMAP-index as defined for the evaluation of the vegetation in the terp region should also be considered to be an analysis by indicator species (Chapter 5 [Schepers *et al.* 2013a]). Based on the typology published by Esselink *et al.* (2009), this index defines how 'salt marsh'-like the landscape around a site is at the ecosystem level, as opposed to using indicator species for specific abiotic values. The salt marsh typology as defined by Esselink *et al.* (2009) includes the brackish marsh and even fresh anthropogenic grasslands. As such, one might speak of a distinction between a salt marsh *'sensu lato'* and a salt marsh *'sensu stricto'*.

In Chapter 5 (Schepers *et al.* 2013a), we use what has been defined as the 'data approach' in Figure 1.1. Both seriation and principal component analysis are used to search for patterning in the data. However, to answer questions that go beyond whether or not there seems to be any interpretable patterning in the data at all, additional, individual species values are required. Moreover, this 'data approach' generally requires a considerably large number of samples. Nonetheless, as an exploratory tool, searching for patterning in the data is of great value, considering the fact that a large and growing corpus of data is available in the Dutch archaeobotanical database RADAR (Van Haaster and Brinkkemper 1995).

In this study, the primary goal was not simply to characterize vegetation in broad terms, but to illustrate and understand the data on a level that optimizes the modelling of its exploitation by humans. In other words, a true reconstruction of vegetation. As long as the spatial relationship between identified taxa is not explored and explained (that is, as long as interpretations are based on individual values alone), the results should not be named a 'vegetation reconstruction', but, rather, a 'characterization of vegetation' (*sensu* Cappers [1994; 1995b]). Once again, I do not mean to imply that these studies are any less useful – merely that they fulfil a different role.

The relationship between taxa can be described through phytosociology or through ecological grouping. Where specific archaeological questions need to be addressed or emphasized, it may be more insightful to use groups such as 'grassland species'

or 'marsh species' than to use possibly related plant communities (Chapter 2 [Schepers *et al*. 2013b]). Although many plants can occur in different places, many studies using ecological groups assign each taxon to a single group for pragmatic reasons, despite acknowledging that this simplification 'muddies' the final interpretation (Neumann *et al*. 1998; Rösch 1996). This kind of single-group labelling is even more hazardous when defining categories for pollen diagrams, where many taxa may present a variety of species, with wide-ranging ecological properties (Behling 1995; Jahns 1996). Evidently, presenting data in diagrams does not allow for double labelling for a taxon. In table form however, it may provide insight, especially for the non-specialist, to emphasize the various types of vegetation in which a taxon may occur. On the other hand, it is the combination of species in a sample that might justify a more precise description (see Chapter 1). For example, a sample containing *Urtica dioica, Alnus glutinosa, Iris pseudacorus,* and *Humulus lupulus* might assign the stinging nettle to an alder carr *(Alnion glutinosae)*, whereas *Urtica dioica* in combination with *Ranunculus sceleratus, Persicaria hydropiper,* and *Bidens tripartita* points to periodically flooded, open banks or shores *(Bidention tripartitae)*.

Actualism | A prime question in vegetation reconstruction, but more especially in phytosociology, is whether or not it is valid to use the 'present as a key to the past' (Behre and Jacomet 1991, 83; see also Chapters 1 and 2 [Schepers *et al*. 2013b] and Chapter 3 [Schepers 2014]). Although this question has been already dealt with in previous chapters, some final remarks will be made here, as prompted by comments by the peer reviewers and editor on Chapter 3 (Schepers 2014), in particular. They pointed out that relying on the actualistic assumption is a hazardous undertaking, especially when taking the analysis to the very detailed level of the plant association or even subassociation. In the relatively recent periods dealt with in this study (second half Holocene), care is especially required when it concerns synanthropic vegetation, such as arable weed communities. Indeed, as shown in Box 1, the method proves capable of identifying an arable weed community for a pure crop sample (buckwheat), but also ex-

cludes some species that must have been part of the arable weed vegetation. However, I would argue that this is equally true for the application of ecological groups to that sample. Neither phytosociology nor ecological groups produce a correct identification of the assemblage in Box 1. It is the combination of the two that leads to a surprisingly detailed reconstruction.

The PALAEOASSOCIA analysis has indeed been carried out in its most extreme form for the Swifterbant area (Chapter 3 [Schepers 2014]), thus triggering the aforementioned objections from colleagues. I would agree that, in general, vegetation that is more natural will suffer less from these constraints. I am convinced, however, that it is justified to apply it to that extent in these types of environments.

The PALAEOASSOCIA method (Chapter 2 [Schepers *et al.* 2013b]) was also used to assess whether a number of halophytes found in Roman deposits in the central Netherlands does indeed point to the importation of plant material from the coast, or whether the taxa concerned could be fit into a naturally occurring local plant community. The fact that it proved impossible to construct an ongoing series of overlapping species groups in the association matrix alone – prior to the actual syntaxon identification – already confirmed that some of the species (the halophytes) were indeed alien to the rest of the dataset (Van den Bos *et al.* 2014).

THE FUTURE OF PAST VEGETATION ECOLOGY I In The Netherlands, archaeobotanical analysis is traditionally performed by biologists (for example, Bakels, Bottema, Brinkkemper, Cappers, Casparie, Kooistra, Pals, Van Haaster, Van Zeist). As pointed out by Brinkkemper *et al.* (2005, 5), the focus on vegetation in past studies is probably at least to some extent explained by this fact. As rightly stated by Jacomet (2007, 2384), "environmental archaeologists are both archaeologists and natural scientists and should have trained in both areas."

The biologically-based archaeobotanists mentioned above all possess(ed) good field training in vegetation science and developed an interest in – and insight into – archaeology. Especially in marginal regions, such as the Dutch wetlands, many cultural phenomena cannot be explained without taking the

necessary cultural adaptations to the constraints of the habitat into consideration (Crawford 2008, especially chapter 11, 'Man at the margins'). The numerous floras, landscape monographs, and handbooks are inadequate to the task; frequent field trips to a variety of landscapes representing all kinds of ecosystems, as well as insights into the basics of geology and geomorphology, are a prerequisite for understanding not only the landscape and the vegetation, but also past human activity. A close cooperation between geologists, ecologists, archaeobotanists and probably agriculturalists will be necessary to fully understand what was going on.

These days, the decision whether to study flora and vegetation is just as much a choice to be made for students of biology, as the decision whether to study archaeobotany is for students of archaeology. Moreover, the complexity of studying past vegetation justifies the recognition of 'past vegetation ecology' as a subdiscipline of either vegetation ecology or archaeobotany. Major parts of this dissertation are the direct result of close cooperation between myself and vegetation ecologists. As such, both people trained primarily in vegetation ecology and those trained primarily in archaeology would need to get acquainted with the theoretical and methodological characteristics of the 'other' discipline to be able to study past vegetation. In my view, both fields serve equally well as a starting point.

As I have argued above, the reconstruction of past vegetation would benefit substantially from sampling in past vegetation systems according to archaeobotanical standards, however odd they may seem from a present-day ecologist's perspective.

In the terps area, sampling creeks and ditches between the settlements will help us to understand how natural the landscape at a greater distance from the terps actually was. The alleged absence of *Elytrigia atherica* grasslands may very well relate to the fact that the signal of these grasslands hardly ever ends up in an archaeobotanical sample.

In addition, a more intense study of the so-called vegetation layers and burn layers is necessary in order to understand why they are there, and how uniform they are over the whole terp region. To address the possibility of 'fire as a grazer' in a salt

marsh environment currently used for nature conservation, it is absolutely necessary to know in what type of vegetation these burning activities took place in the past.

A final recommendation is to not only analyze new samples, but to also benefit from the fact that many samples have been studied over the past decades that have as yet only been used on a site level. In Chapter 5 (Schepers *et al*. 2013a), the combined analysis of a large number of samples from throughout the terps area shows that lots can be learned from datasets that are already available.

Notes

1 In the following discussion, the number in parentheses following a place name relates to the location of that site in Figure 5.1.

2 Brinkkemper *et al*. (2005) speak of 'wild flora' here, where the term vegetation would have been more appropriate.

3 Personal communication from Cappers, 2010

4 Personal communication, September 2013

5 As opposed to reconstruction of vegetation.

References

Aalbersberg G, Huisman DJ (in prep) Geolandschappelijk onderzoek Werpsterhoek en archeologische begeleiding dijkdoorsnijding Bredyk, gemeente Leeuwarden (=RAAP-rapport). RAAP Archeologisch Adviesbureau, Weesp

Acker Stratingh G (1852) Aloude staat en geschiedenis des vaderlands, deel 2. De bewoners. R.J. Schierbeek, Groningen

Adam P (1990) Salt marsh ecology. Cambridge University Press, Cambridge

Akeret Ö, Haas JN, Lezinger U, Jacomet S (1999) Plant macrofossils and pollen in goat/sheep faeces from the Neolithic lake-shore settlement Arbon Bleiche 3, Switzerland. The Holocene 9:175-182

Anon (2011) Nieuwe atlas van de Nederlandse flora. KNNV, Zeist

Araújo BA, Rozenfeld A, Rahbek C, Marguet PA (2011) Using species co-occurrence networks to assess the impacts of climate change. Ecography 34:897-908

Arnolds E, Van der Maarel E (1979) De oecologische groepen in de Standaardlijst van de Nederlandse flora 1975. Gorteria 9:303-312

Bakels CC (1978) Four linearbandkeramik settlements and their environment: a palaeoecological study of Sittard, Stein, Elsloo and Hienheim. Dissertation, Leiden University

Bakels CC (2000) Pollen diagrams and prehistoric field: the case of Bronze Age Haarlem, the Netherlands. Rev Palaeobot Palynol 109:205-218

Bakels CC, Van Beurden LM, Vernimmen TJJ (2001) Archeobotanie. In: Louwe Kooijmans LP (ed) Archeologie in de Betuweroute. Hardinxveld-Giessendam, De Bruin (=Rapportage Archeologische Monumentenzorg 85). Rijksdienst voor het Oudheidkundig Bodemonderzoek, Amersfoort, pp 369-434

Bakels CC, Zeiler JT (2005) The fruits of the land: Neolithic subsistence. In: Louwe Kooijmans LP, Van den Broeke PW, Fokkens H, Van Gijn AL (eds) The prehistory of the Netherlands. Amsterdam University Press, Amsterdam, pp 311-335

Bakker JP (1983) Use and management of salt marshes on sand-dune islands. In: Dijkema KS, Wolff WJ (eds) Flora and vegetation of the Wadden Sea islands and coastal areas. Balkema, Rotterdam, pp 290-302

Bakker JP (1989) Nature management by grazing and cutting. Dissertation, University of Groningen

Bakker JP (2012) Restoration of salt marshes. In: Van Andel J, Aronson J (eds) Restoration ecology: the new frontier, 2nd edition. Blackwell Publishing, Oxford, pp 248-262

Bakker JP, Bunje J, Dijkema KS, Frikke J, Kers B, Körber P, Kohlus J, Stock M (2005) Salt marshes. In: Essink K, Dettmann C, Farke H, Laursen K, Lüerβen G, Marencic H, Wiersinga W (eds) Wadden Sea quality status report 2004 (=Wadden Sea Ecosystem No. 19). Trilateral Monitoring and Assessment Group, Common Wadden Sea Secretariat. Wilhelmshaven, pp 163-179

Bakker JP, Gálvez Bravo L, Mouissie AM (2008) Dispersal by cattle of salt-marsh and dune species into salt-marsh and dune communities. Plant Ecol 197:43-54

Bakker JP, Remans K, Bekker RM, Steendam H, Van Gompel J, Hermy M (2009) Herstel van zilte graslanden in Vlaamse kustpolders. De Levende Natuur 110:220-224

Bakker M (2013) Op het spoor van de vroegste veenontginningen in Westergo. Het archeologisch onderzoek van een nederzetting uit de late ijzertijd en Romeinse tijd bij Arkum, Friesland. Master thesis, University of Groningen

Bazelmans J, Gerrets D, De Koning J, Vos P (1999) Zoden aan de dijk. Kleinschalige dijkbouw in de late prehistorie en protohistorie van noordelijk Westergo. De Vrije Fries 79:7-74

Bazelmans J, Groenendijk H, De Langen G, Nicolay J, Nieuwhof A (2009) De late prehistorie en protohistorie van Holoceen Noord-Nederland, versie 2.0. Waddenacademie, Leeuwarden

Bazelmans J, Meier D, Nieuwhof A, Spek T, Vos P (2012) Understanding the cultural historical value of the Wadden Sea region. The co-evolution of environment and society in the Wadden sea area in the Holocene up until early modern times (11,700 BC–1800 AD). Ocean Coast Manag 68:114-126

Bazzaz FA, Ackerly DD, Woodward FI, Rochefort L (1992) CO2 enrichment and dependence of reproduction on density in an annual plant and a simulation of its population dynamics. J Ecol 80:643-651

Beeftink WG (1965) De zoutvegetatie van ZW-Nederland beschouwd in Europees verband. Dissertation, Wageningen University

Beeftink WG, Daane MC, De Munck W, Nieuwenhuize J (1978) Vegetation dynamics in salt marshes as a consequence of some traditional cultural practices of man. Phytocoenosis 7:279-298

Behling H (1995) Investigations into the late Pleistocene and Holocene history of vegetation and climate in Santa Catarina (S Brazil). Veg Hist Archaeobot 4:127-152

Behre K-E (1970) Die Entwicklungsgeschichte der natürlichen Vegetation im Gebiet der unteren Ems und ihre Abhängigkeit von den Bewegungen des Meeresspiegels. Probl Küstenforsch südl Nordseegeb 9:13-47

Behre K-E (1976) Die Pflanzenreste aus der frühgeschichtlichen Wurt Elisenhof. Herbert Lang/ Peter Lang, Bern/Frankfurt am Main

Behre K-E (1979) Zur rekonstruktion ehemaliger Pflanzengesellschaften an der Deutschen Nordseeküste. In: Willmans O, Tüxen R (eds) Werden und Vergehen von Pflanzengesellschaften. Cramer, Vaduz, pp 181-214

Behre K-E (1985) Die ursprüngliche Vegetation in den Deutschen Marschgebieten und deren Veränderung durch prähistorischen Besiedlung und Meeresspiegelbewegungen. Verh Ges Ökol 13:85-96

Behre K-E (1991) Umwelt und Ernährung der frühmittelalterlichen Wurt Niens/Butjadingen nach den Ergebnissen der botanischen Untersuchungen. Probl Küstenforsch südl Nordseegeb 18:141-168

Behre K-E (2008) Landschaftsgeschichte Norddeutschlands. Umwelt und Siedlung von der Steinzeit bis zur Gegenwart. Wachholtz, Neumünster

Behre K-E, Jacomet S (1991) The ecological interpretation of archaeobotanical data. In: Van Zeist W, Wasylikowa K, Behre K-E (eds) Progress in old world palaeoethnobotany. Balkema, Rotterdam, pp 81-108

Beijerinck W (1929) De subfossiele plantenresten in de terpen van Friesland en Groningen. eerste gedeelte: vruchten, zaden en bloemen. Stichting Fonds Landbouw Export Bureau 1916-1918, Wageningen

Beijerinck W (1931) De subfossiele plantenresten in de terpen van Friesland en Groningen. Derde en laatste gedeelte: overige macro- en microscopische resten. Stichting Fonds Landbouw Export Bureau 1916-1918, Wageningen

Beijerinck W (1947) Zadenatlas der nederlandsche flora. H. Veenman & zonen, Wageningen

Bekker RM, Verweij GL, Bakker JP, Fresco LFM (2000) Soil seed bank dynamics in hayfield succession. J Ecol 88:594-607

Beneš J, Kaštovský J, Kočárová R, Koč P, Kubečková K, Pokorný P, Starec P (2002) Archaeobotany of the old Prague town defence system, Czech Republic: archaeology, macro-remains, pollen, and diatoms. Veg Hist Archaeobot 11:107-110

Berendsen HJA (2004) De vorming van het land: inleiding in de geologie en de geomorfologie. Van Gorcum, Assen

Berggren W (1969) Atlas of seeds and small fruits of Northwest-European plant species. Part 2. Cyperaceae. Swedish Museum of Natural History, Stockholm

Berglund BE, Emanuelsson U, Persson S, Persson T (1986) Pollen/vegetation relationships in grazed and mowed plant communities of South Sweden. In Behre K-E (ed) Anthropogenic indicators in pollen diagrams. Balkema, Rotterdam, pp 37-51

Bieleman J (1987) Boeren op het Drentse zand 1600–1910. Een nieuwe visie op de oude landbouw. H&S, Utrecht

Bierma M, Clason AT, Kramer, E, De Langen GJ (eds, 1988) Terpen en wierden in het Fries-Groningse kustgebied. Wolters-Noordhoff, Groningen

Birks HH (1973) Modern macrofossils in lake sediments in Minnesota. In: Birks HJB, West RG (eds) Quaternary plant ecology. Blackwell Scientific, Oxford, pp 173-189

Birks HH, Birks HJB (2005) Reconstructing Holocene climates from pollen and plant macrofossils. In: Mackay A, Battarbee R, Birks J, Oldfield F (eds) Global change in the Holocene. Hodder Arnold, London, pp 342-357

Birks HH, Birks HJH (2006) Multi-proxy studies in palaeolimnology. Veg Hist Archaeobot 15:235-251

Boedeltje G, Bakker JP, Ten Brinke A, Van Groenendael JM, Soesbergen M (2003) Plant dispersal in a lowland stream in relation to occurrence and three specific life-history traits of the species in the species pool. J Ecol 91:855-866

Boeles PCJA (1951) Friesland tot de elfde eeuw. Zijn vóór- en vroege geschiedenis. Martinus Nijhoff, The Hague

Boersma JW (ed, 1970) Terpen. Mens en milieu. Knoop & Niemeijer, Haren

Boersma JW (2005) De trek naar de klei. De bewoning van het noordelijke kustgebied. In: Louwe Kooijmans LP, Van den Broeke PW, Fokkens H, Van Gijn A (eds) Nederland in de prehistorie. Bert Bakker, Amsterdam, pp 561-576

Bogaard A (2004) Neolithic farming in central Europe. An archaeobotanical study of crop husbandry practices. Routledge, London/New York

Bogaard A (2008) Comment on R.T.J. Cappers and D.C.M. Raemaekers: Cereal cultivation at Swifterbant? Neolithic wetland farming on the North European Plain. Curr Anthropol 49:394-395

Bogaard A, Jones G, Charles M, Hodgson JG (2010) Crops and weeds: the role of weed functional ecology in the identification of crop husbandry methods. J Archaeol Sci 37:70-77

Bohncke SJP (1984) Palaeobotanical study on vegetation horizons in the young Holocene coastal plain of Groningen (northern Netherlands). In: Schoute JFTh (ed) Vegetation horizons and related phenomena. A palaeoecological-micromorphological study in the younger coastal Holocene of the northern Netherlands (Schildmeer area). Dissertation, VU University Amsterdam

Bos JAA, Verbruggen F, Engels S, Crombé P (2013) The influence of environmental change on local and regional vegetation patterns at Rieme (NW Belgium): implications for Final Palaeolithic habitation. Veg Hist Archaeobot 22:17-38

Bottema S (1984) The composition of modern charred seed assemblages. In: Van Zeist W, Casparie WA (eds) Plants and ancient man. Studies in palaeoethnobotany. Balkema, Rotterdam, pp 25-51

Bottema S, Van Hoorn TC, Woldring H, Gremmen WHE (1980) An agricultural experiment in the unprotected salt marsh. Part II. Palaeohist 22:127-140

Bottema-Mac Gillavry JM (2010) Scheepshout en andere houtvondsten. In: Nicolay JAW (ed) Terpbewoning in oostelijk Friesland. Twee opgravingen in het voormalige kweldergebied van Oostergo (=Groningen Archaeological Studies 10). Barkhuis, Eelde, pp 155-162

Bottema-Mac Gillavry JM (2011) Hout en houtskool. In: Tuinstra JAW, Veldhuis JR, Nicolay JAW (eds) Hallum, een welvarend dorp aan de monding van de Middelzee. Een archeologische opgraving te Hallum, gemeente Ferwerderadeel (Fr.) (=ARC-Publicaties 205). ARC, Groningen, pp 223-233

Bozilova E, Beug H-J (1992) On the Holocene history of vegetation in SE Bulgaria (Lake Arkutiono, Ropotamo region). Veg Hist Archaeobot 1:19-32

Braadbaart F, Poole I, Huisman HDJ, Van Os B (2012) Fuel, fire and heat: an experimental approach to highlight the potential of studying ash and char remains form archaeological contexts. J Archaeol Sci 39:836-847

Bradshaw M, Weaver R (1995) Foundations of physical geography. Wm. C. Brown, Dubuque

Braun-Blanquet J (1964) Pflanzensoziologie, Grundzüge der Vegetationskunde. (3. Auflage). Springer, Wien

Brinkhuizen DC (1976) De visresten van Swifterbant. Westerheem 25:246-252

Brinkkemper O (1993) Wetland farming in the area to the south of the Meuse estuary during the Iron Age and Roman Period. Dissertation, Leiden University

Brinkkemper O (2006) Wetlands en menselijke bestaansmogelijkheden in de late prehistorie. In: Brinkkemper O, Deeben J, Van Doesburg J, Hallewas DP, Theunissen EM, Verlinde AD (eds) Vlakken in vakken. Archeologische kennis in lagen (=Nederlandse Archeologische Rapporten 32). Rijksdienst voor het Oudheidkundig Bodemonderzoek, Amersfoort, pp 21-40

Brinkkemper O, Brongers M, Jager S, Spek T, Van der Vaart J, IJzerman Y (2009) De Mieden: een landschap in de noordelijke Friese Wouden. Matrijs, Utrecht

Brinkkemper O, Kooistra LI, Van Haaster H, Van Beurden L, Bunnik F (2005) Archeobotanie National Archaeological Research Agenda (NOaA), chapter 9 (version 1.0). http://archeologieinnederland.nl/sites/default/files/9%20Botanie.pdf. Accessed 23 March 2014

Brinkkemper O, Van Haaster H (2010) Delfts groen. Archeobotanisch onderzoek aan Delft-Voordijkshoornsepolder, een nederzetting uit 1075–1150 (=BIAXiaal 430). BIAX Consult, Zaandam

Britton K, Müldner G, Bell M (2008) Stable isotope evidence for salt-marsh grazing in the Bronze Age Severn Estuary, UK: implications for palaeodietary analysis at coastal sites. J Archaeol Sci 35:2111-2118

Bromberg Gedan K, Silliman BR, Bertness MD (2009) Centuries of human-driven change in salt marsh ecosystems. Ann Rev Mar Sci 1:117-141

Broström A (2002) Estimating source area of pollen and pollen productivity in cultural landscapes of southern Sweden – developing a palynological tool for quantifying past plant cover. Dissertation, Lund University

Broström A, Gaillard MJ, Ihse M, Odgaard B (1998) Pollen-landscape relationships in modern analogues of ancient cultural landscapes in southern Sweden – a first step towards quantification of vegetation openness in the past. Veg Hist Archaeobot 7:189-201

Brul P (2012) Salty farming in salty conditions. Ecol Farming 1:18-20

Bunting MJ (2003) Pollen-vegetation relationships in non-arboreal moorland taxa. Rev Palaeobot Palynol 125:285-298

Butzer KW (1982) Archaeology as human ecology. Cambridge University Press, Cambridge

Buurman J (1996) The eastern part of West-Friesland in later prehistory. Agricultural and environmental aspects. Dissertation, Leiden University

Buurman J (1999) Archaeobotanical investigations of a Middle and Late Bronze Age settlement site at Westwoud (West-Friesland). Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek 43: 99-140

Cappers RTJ (1993) Seed dispersal by water: a contribution to the interpretation of seed assemblages. Veg Hist Archaeobot 2(3):173-186

Cappers RTJ (1994) An ecological characterization of the Holocene palaeobotanical record of the Netherlands. Acta Bot Neerl 43:145-174

Cappers RTJ (1995a) A palaeoecological model for the interpretation of wild plant species. Veg Hist Archaeobot 4:249-257

Cappers RTJ (1995b) Botanical macro-remains of vascular plants of the Heveskesklooster terp (the Netherlands) as tools to characterize the past environment. Palaeohist 35/36:107-169

Cappers RTJ (2006) The reconstruction of agricultural practices in ancient Egypt: an ethnoarchaeobotanical approach. Palaeohist 47/48:429-446

Cappers RTJ (2008) Onderzoek aan macroscopische plantenresten. In: Nicolay JAW, Dijkstra J (eds) Een terp op de schop. Archeologisch onderzoek op het Oldehoofsterkerkhof te Leeuwarden (=ADC Monografie 3). ADC Archeoprojecten, Amersfoort, pp 233-258

Cappers RTJ, Bekker RM (2013) A manual for the identification of plant seeds and fruits. Barkhuis, Eelde

Cappers RTJ, Bekker RM, Jans JEA (2006) Digital seed atlas of the Netherlands (=Groningen Archaeological Studies 4). Barkhuis, Eelde

Cappers RTJ, Neef R (2012) Handbook of plant palaeoecology (=Groningen Archaeological Studies 19). Barkhuis, Eelde

Cappers RTJ, Raemaekers DCM (2008) Cereal cultivation at Swifterbant? Neolithic wetland farming on the North European Plain. Curr Anthropol 49:385-402

Cappers RTJ, Van Zanten BO (1994) Ecology and representativeness of subfossil mosses from the Heveskesklooster terp (the Netherlands). Lindbergia 18:106-115

Cappers RTJ, Vrede F, Dopmeijer H (2005) Plantenresten uit de Friesestraatweg-Wierde. Hervonden Stad 10:93-104

Carrión JS (2002) A taphonomic study of modern pollen assemblages from dung and surface sediments in arid environments of Spain. Rev Palaeobotany Palynol 120:217-232

Carrión JS, Scott L, Huffman T, Dreyer C (2000) Pollen analysis of Iron Age cow dung in southern Africa. Veg Hist Archaeobot 9:239-249

Caseldine C (1982) Palynological evidence for early cereal cultivation in Strathearn. Proc Soc Antiq Scot 112:39-47

Caseldine C, Pardoe H (1994) Surface pollen studies from alpine/sub-alpine southern Norway: applications to Holocene data. Rev Palaeobot Palynol 82:1-15

Casparie WA (1970) The wood remains of Paddepoel. Palaeohist 14:284-285

Casparie WA (1972) Bog development in southeastern Drenthe (the Netherlands). Dissertation, University of Groningen

Casparie WA, Mook-Kamps B, Palfenier-Vegter RM, Struijk PC, Van Zeist W (1977) The palaeobotany of Swifterbant: a preliminary report. Helinium 17:28-55

Chang ER, Veeneklaas RM, Buitenwerf R, Bakker JP, Bouma TJ (2008) To move or not to move: determinants of seed retention in a tidal marsh. Func Ecol 22:720-727

Charles M (1998) Fodder from dung: the recognition and interpretation of dung-derived plant material from archaeological sites. Environ Archaeol 1:111-22

Charles M, Jones G, Hodgson JG (1997) FIBS in Archaeobotany: functional interpretation of weed floras in relation to husbandry practices. J Archaeol Sci 24:1151-1161

Claassen T (1983) Ringdobben. Waddenbull 18:203-206

Clark JS (1986) Late-Holocene vegetation and coastal processes at a long island tidal marsh. J Ecol 74:561-578

Clarke C (2013) Palaeoecological reconstructions. In: Menotti F, O'Sullivan A (eds) The Oxford handbook of wetland archaeology. Oxford University Press, Oxford, pp 539-554

Clason AT, Brinkhuizen DC (1978) Swifterbant. Mammals, birds, fishes. A preliminary report. Helinium 17:28-55

Cleveringa P (1974) Pollenanalytische gegevens van de Wold Formatie Noordoost-Friesland. In: Griede JW (ed) Het ontstaan van Frieslands noordhoek. Rodopi, Amsterdam

Coppens CFH (2009) Gasleidingtracé Swifterbant-Emmeloord (A-683 en N-500-64) Gemeenten Dronten en Noordoostpolder: archeologisch vooronderzoek: een inventariserend veldonderzoek (verkennende en karterende fase)(=RAAP-rapport 1873). RAAP, Weesp

Cosyns E, Hoffmann M (2005) Horse dung germinable seed content in relation to plant species abundance, diet composition and seed characteristics. Basic Appl Ecol 6:11-24

Court-Picon M, Buttler A, Beaulieu J-L (2005) Modern pollen-vegetation relationships in the Champsaur valley (French Alps) and their potential in the interpretation of fossil pollen records of past cultural landscapes. Rev Palaeobotany Palynol 135:13-39

Couvreur M, Cosyns E, Hermy M, Hoffmann (2005) Complementarity of epi- and endozoochory of plant seeds by free ranging donkeys. Ecography 28:37-48

Crawford RMM (2008) Plants at the margin. Ecological limits and climate change. Cambridge University Press, Cambridge

Crawley MJ (1992) Seed predators and plant population dynamics. In: Fenner M (ed) Seeds. The ecology of regeneration in plant communities. Redwood Press, Melksham, pp 157-191

Davies BR, Biggs J, Williams PJ, Lee JT, Thompson S (2008) A comparison of the catchment sizes of rivers, streams, ponds, ditches and lakes: implications for protecting aquatic biodiversity in an agricultural landscape. Hydrobiol 597:7-17

De Langen G (2012) Vensters op Frisia. Over nut en noodzaak van het universitaire terpenonder-zoek (=Jaarversl Ver Terpenonderz 95). Vereniging voor Terpenonderzoek, Groningen

De Moor JJW, Bos JAA, Bouman MTIJ, Moolhuizen C, Exaltus R, Maartense FPA, Van der Linden TJM (2009) Definitief archeologisch onderzoek in het tracé van de Hanzelijn in het Nieuwe Land. Deltares, Delft

De Mulder EFJ, Geluk MC, Ritsema I, Westerhoff WE, Wong TE (2003) De ondergrond van Nederland. Wolters-Noordhoff, Groningen

De Roever JP (1976) Excavations at the river dune sites S21-22. Helinium 16:209-221

De Roever JP (2004) Swifterbant-aardewerk: een analyse van de neolithische nederzettingen bij Swifterbant, 5e millennium voor Christus (=Groningen Archaeological studies 2). Dissertation, University of Groningen

De Roller GJ (1999a) De macroresten. In: De Roller GJ, Stuijts I-LM (eds) Een palaeo-botanisch onderzoek bij Hempens-Teerns, gem. Leeuwarden (=ARC-Publicaties 25). ARC, Groningen, pp 7-24

De Roller GJ (1999b) Palaeobotanisch onderzoek. In: Huisman MA, Huizenga B, Tuinstra SJ, Stuijts I-LM, De Roller GJ, Bakker AM, Halici H (eds) Archeologisch onderzoek op de nieuwbouwlocatie Bollemans-steeg te Leeuwarden, gemeente Leeuwarden (=ARC-Publicaties 28). ARC, Groningen, pp 25-29

De Roller GJ (2000) Bijlage II: archeobotanisch onderzoek. In: Koopstra CG, Halici H, De Roller GJ (eds) Archeologisch onderzoek op het NAM-tracé Munnekezijl-Saaksum te Aalsum, gemeente Zuidhorn (=ARC-Publicaties 37). ARC, Groningen, pp 20-22

De Roller GJ (2002a) Archeobotanisch onderzoek. In: Koopstra CG (ed) Archeologisch onderzoek in de Bullepolder, gemeente Leeuwarden (=ARC-Publicaties 52). ARC, Groningen, pp 55-60

De Roller GJ (2002b) Botanische macroresten. In: Niekus MJLTh, Huisman, MA (eds) Een huisterpje uit de Romeinse tijd in het veen-kleigebied. Een archeologische opgraving in het tracé van de stadsrondweg Oost te Sneek, gemeente Sneek (Fr.) (=ARC-Publicaties 53). ARC, Groningen, pp 87-98

De Roller GJ (2002c) Botanisch materiaal. In: Niekus MJLTh (ed) Archeologisch onderzoek van een vroegmiddeleeuws terpje bij Sneek, gem. Sneek, Friesland (=ARC-publicaties 54). ARC, Groningen, pp 35-52

De Roller GJ (2002d) Botanisch materiaal en hout. In: Hielkema JB (ed) Archeologisch onderzoek bij de Boltastate in Harlingen, provincie Friesland (=ARC-Publicaties 55). ARC, Groningen, pp 23-26

De Roller GJ, Korf G (2002) Archeobotanie. In: Koopstra CG (ed) Archeologisch onderzoek op de wierde van Baflo, provincie Groningen (=ARC-Publicaties 47). ARC, Groningen, pp 25-36

De Wolf H, Cleveringa P (2005) Swifterbant: nat maar begroeid, wonen in een estuarium. TNO, Utrecht

De Wolf H, Cleveringa P (2006) Paleoecologisch diatomeeënonderzoek van twee ontsluitings-profielen te Swifterbant, Oostelijk Flevoland. TNO, Utrecht

De Wolf H, Cleveringa P (2009a) Paleoecologisch diatomeeënonderzoek van drie ontsluitingspro-fielen genomen in 2006 te Swifterbant, Oostelijk Flevoland. PalaeoDiat/WMC Kwartair Consultants, Beverwijk

De Wolf H, Cleveringa P (2009b) Paleoecologisch diatomeeënonderzoek van S4-put 1 (bak 1 en 2) en van het lakprofiel te Swifterbant, Oostelijk Flevoland. PalaeoDiat/WMC Kwartair Consultants, Beverwijk

Deckers PH, De Roever JP, Van der Waals JD (1980) Jagers, vissers en boeren in een prehistorisch getijdengebied bij Swifterbant. Z.W.O.-Jaarboek 1980:111-145

Deforce K (2011) Middle and late Holocene vegetation and landscape evolution of the Scheldt estuary: a palynological study of a peat deposit from Doel (N-Belgium). Geol Belg 14:277-288

Deforce K, Bastiaens J, Van Neer W, Ervynck A, Lentacker A, Sergant J, Crombé P (2013) Wood charcoal and seeds as indicators for animal husbandry in a wetland site during the Late Mesolithic–Early Neolithic transition period (Swifterbant culture, ca. 4600–4000 B.C.) in NW Belgium. Veg Hist Archaeobot 22:51-60

Dejean T, Valentini A, Duparc A, Pellier-Cuit S, Pompanon F, Taberlet P, Miaud C (2011) Persistence of environmental DNA in freshwater ecosystems. PLoS One 6(8):e23398

Delcourt HR (1987) The impact of prehistoric agriculture and land occupation on natural vegetation. Trends Ecol Evol 2:39-44

Den Hartog C (2001) Waarnemingen aan akkeronkruidvegetaties. Stratiotes 23:14-21

Devriendt I (2013) Swifterbant stones. The neolithic stone and flint industry at Swifterbant (the Netherlands): from stone typology and flint technology to site function. Dissertation, University of Groningen

Dieffenbacher-Krall AC (2007) Surface samples, taphonomy, representation. In: Elias AE (ed) Encyclopedia of quaternary science. Elsevier, Oxford, pp 2367-2374

Dijkema KS (1983) Use and management of mainland salt marshes and Halligen. In: Dijkema KS, Wolff WJ (eds) Flora and vegetation of the Wadden Sea islands and coastal areas. Balkema, Rotterdam, pp 302-322

Dijkema KS (1984) Northern Europe. In: Dijkema KS (ed) Salt marshes in Europe. European Committee for the Conservation of Nature and Natural Resources, Strasbourg, pp 150-151

Dijkema KS (1987) Changes in salt marsh area in the Netherlands Wadden Sea after 1600. In: Huiskes AHL, Blom CWPM, Rozema J (eds) Vegetation between land and sea. Dr. W. Junk, Dordrecht/Boston/Lancaster, pp 42-49

Dijkema KS (1990) Salt and brackish marshes around the Baltic Sea and their adjacent parts of the North Sea: their vegetation and management. Biol Conserv 51:191-209

Doody JP (2004) ‚Coastal squeeze' – an historical perspective. J Coast Conserv 10:129-138

Dresscher S, Raemaekers DCM (2010) Oude geulen op nieuwe kaarten. Het krekensysteem bij Swifterbant (Fl.). Paleo-aktueel 21:31-37

Dybkjær JB, Baattrup-Pedersen A, Kronvang B, Thodsen H (2011) Diversity and distribution of riparian plant communities in relation to stream size and eutrophication. J Environ Qual 41:348-354

Eggers T (1979) Werden und Wandel der Ackerunkraut-vegetation. In: Willmans O, Tüxen R (eds) Werden und Vergehen von Pflanzengesellschaften. Cramer, Vaduz, pp 503-527

Eijskoot Y, Brinkkemper O, De Ridder T (eds, 2011) Vlaardingen-De Vergulde Hand-West. Onderzoek van archeologische resten van de middenbronstijd tot en met de late middeleeuwen (=Rapportage Archeologische Monumentenzorg 200). Rijksdienst voor het Cultureel Erfgoed, Amersfoort

Eisma D, Dijkema KS (1998) The influence of salt marsh vegetation on sedimentation. In: Eisma D (ed) Intertidal deposits: river mouths, tidal flats, and coastal lagoons. CRC Press, Boca Raton, pp 403-414

Ellenberg H, Weber HE, Düll R, Wirth V, Werner W, Paulissen D (1991) Zeigerwerte von Pflanzen in Mitteleuropa. Scr Geobot 18:1-248

Ente PJ (1976) The geology of the northern part of Flevoland in relation to the human occupation in the Atlantic time. Helinium 16:1536

Esselink P (2000) Nature management and coastal salt marshes. Dissertation, University of Groningen

Esselink P, Petersen J, Arens S, Bakker JP, Bunje J, Dijkema KS, Hecker N, Hellwig U, Jensen A-V, Kers AS, Körber P, Lammerts EJ, Stock M, Veeneklaas RM, Vreeken M, Wolters M (2009) Salt marshes. Thematic Report No. 8. In: Marencic H, De Vlas J (eds) Quality status report 2009 (=Wadden Sea Ecosystem No. 25). Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven

Everts FH, De Vries NPJ (1991) De vegetatieontwikkeling van beekdalsystemen. Een landschaps-oecologische studie van enkele Drentse beekdalen. Historische Uitgeverij, Groningen

Exaltus RP, Kortekaas GLGA (2008) Prehistorische branden op Groningse kwelders. Paleo-aktueel 19:115-124

Faegri K, Iversen J (1989) Textbook of pollen analysis (4th edition). Wiley, Chichester

Fenner M (1985) Seed ecology. Chapman and Hall, London/New York

Gaillard M-J, Birks, HH (2013) The contribution of plantmacrofossil analysis to paleolimnology. In: Elias AE (ed) Encyclopedia of quaternary science. Elsevier, Oxford, pp 657-673

Gee JHR, Giller PS (1991) Contemporary community ecology and environmental archaeology. In: Harris DR, Thomas KD (eds) Modelling ecological change. Perspectives from neoecology, palaeoecology and environmental archaeology. University College London, London, pp 1-16

Gehasse EF (1995) Ecologisch-archeologisch onderzoek van het Neolithicum en de Vroege Bronstijd in de Noordoostpolder met de nadruk op vindplaats P14. Dissertation, University of Amsterdam

Gerrets DA (2010) Op de grens van land en water. Dissertation, University of Groningen

Geuverink J, Raemaekers DCM, Devriendt I (2009) Op zoek naar archeologie bij Doug's duin. Kamperhoekweg, Swifterbant, Gemeente Dronten: inventariserend veldonderzoek door middel van boringen (=Grondsporen 4). Groningen Institute of Archaeology, Groningen

Gifford DP (1981) Taphonomy and palaeoecology: a critical review of archaeology's sister disciplines. Archaeol Method Theory 4:365-438

Glenn EP, Brown JJ (1999) Salt tolerance and crop potential of halophytes. Crit Rev Mar Sci 18:227-255

Godefroid S, Dana ED (2007) Can Ellenberg's indicator values for Mediterranean plants be used outside their region of definition? J Biogegr 34:62-68

Gotjé W (1993) De Holocene laagveenontwikkeling in de randzone van de Nederlandse kustvlakte (Noordoostpolder). Dissertation, VU University Amsterdam

Griede JW (1978) Het ontstaan van Frieslands noordhoek. Rodopi, Amsterdam

Griffiths HI (2007) Non-marine ostracods as indicator taxa in ancient wetlands. In: Lillie M, Ellis S (eds) Wetland archaeology and environments. Regional issues, global perspectives. Oxbow Books, Oxford, pp 186-197

Groenendijk HA (2008) Groningen in de prehistorie. In: Santing CG (ed) Geschiedenis van Gronin- gen 1. Prehistorie-Middeleeuwen. Waanders, Zwolle, pp 22-99

Groenman-van Waateringe W (1986) Grazing possibilities in the Neolithic of the Netherlands based on palynological data. In: Behre K-E (ed) Anthropogenic indicators in pollen diagrams. Balke- ma, Rotterdam, 187-202

Groenman-van Waateringe W (1992) Palynology and archaeology: the history of a plaggen soil from the Veluwe, the Netherlands. Rev Palaeobot Palynol 73:87-98

Grootjans AP, Van Diggelen R, Joosten H, Smolders AJP (2012) Restoration of mires. In: Van Andel J, Aronson J (eds) Restoration ecology: the new frontier, 2nd edition. Blackwell Publishing, Oxford, pp 203-213

Hall A, Kenward H (1996) Disentangling dung: pathways to stable manure. Environ Archaeol 1:87-94

Hamburg T, Müller A, Quadflieg B (eds, 2013) Mesolithisch Swifterbant (=Archol rapport 174/ADC rapport 3250). Archol/ADC Archeoprojecten, Leiden/Amersfoort

Hammer Ø, Harper DAT, Ryan PD (2001) PAST: palaeontological statistics software package for education and data analysis. Palaeontol Electron 4

Hänninen K, Den Ouden N, Van Rijn P, Vorst Y (2008) Constructiehout en houten voorwerpen. In: Nicolay JAW, Dijkstra J (eds) Een terp op de schop. Archeologisch onderzoek op het Oldehoof- sterkerkhof te Leeuwarden (=ADC Monografie 3). ADC Archeoprojecten, Amersfoort, pp 191-210

Hänninen K, Van Waijen M (2005) De Stinswier van Sneek. Resultaten van archeobotanisch onderzoek aan materiaal uit de 12e en 13e eeuw (=BIAXiaal 237). BIAX Consult, Zaandam

Haveman R, Schaminée JHJ, Weeda EJ (1998) Stellarietea mediae. In: Schaminée JHJ, Weeda EJ, Westhoff V (eds) De vegetatie van Nederland. Volume 4. Opulus, Uppsala, pp 199-246

Havinga AJ, Van den Berg van Saparoea RM (1992) Pollen and macrofossil analysis of a unique peat remnant of the former extensive peat bogs in West Friesland, the Netherlands: a detailed record of coastal raised bog formation. Veg Hist Archaeobot 1:185-188

Hennekens SM, Schaminée JHJ (2001) TURBOVEG, a comprehensive database management system for vegetation data. J Veg Sci 12:589-591

Hennekens SM, Smits NAC, Schaminée JHJ (2010) SynBioSys Nederland versie 2. Alterra, Wageningen

Hillman G (1991) Phytosociology and ancient weed floras: taking account of taphonomy and changes in cultivation methods. In: Harris DR, Thomas KD (eds) Modelling ecological change. Perspectives from neoecology, palaeoecology and environmental archaeology. University College London, London, pp 27-40

Hogestijn JWH (1989) Palaeobotanical analysis of Monnickendam and the salination of the Zuiderzee. In: Heidinga HA, Van Regteren Altena HH (eds) Medemblik and Monnickendam: aspects of medieval urbanization in northern Holland (=Cingula 11), Amsterdam, pp 115-124

Holyoak DT (1984) Taphonomy of prospective plant macrofossils in a river catchment on Spitsbergen. New Phytol 98:405-423

Hondelink M (2012) Archeobotanisch onderzoek naar de dorpsterp van Jelsum (Fr.). Een vergelijkend onderzoek van archeobotanische veldresiduen en labresiduen. Unpublished student report, University of Groningen

Huis in 't Veld JY (2010) Bodemontwikkeling. In: Huis in 't Veld J (ed) Wonen op een huiswierde in de Late Middeleeuwen en Nieuwe Tijd. Archeologisch onderzoek in de toekomstige nieuwbouw-wijk de held III te Groningen (=Stadse Fratsen 22). Stichting Monument en Materiaal/Gemeente Groningen, Dienst RO/EZ, Groningen, pp 5-7

Huisman DJ, Jongmans AG, Raemaekers DCM (2009) Investigating Neolithic land use in Swifterbant (NL) using micromorphological techniques. Catena 78:85-197

Hullegie AGJ (2009) Swifterbant S4: archeo-ichtyologisch onderzoek vlak 3 en 9. Bachelor thesis, University of Groningen

Huntley J (2012) Carex nutlet project. http://www.dur.ac.uk/j.p.huntley/research_sites/carex-1.html. Accessed 23 March 2014

Jackson ST, Williams JW (2004) Modern analogs in Quaternary: here today, gone yesterday, gone tomorrow? Ann Rev Earth Planet Sci 32:495-537

Jacomet S (2007) Use in environmental archaeology. In: Elias AE (ed) Encyclopedia of quaternary Science, Elsevier, Oxford, pp 2384-2412

Jacomet S (2013) Archaeobotany. Analyses of plant remains from waterlogged archaeological sites. In: Menotti F, O'Sullivan A (eds) The Oxford handbook of wetland archaeology. Oxford University Press, Oxford, pp 497-514

Jacomet S, Kreutz A (1999) Archäobotanik. Ulmer, Stuttgart

Jager HJ, Rintjema S (2011) De biodiversiteit van de Noord-Friese vastelandskust. Een overzicht van wat er tot dusverre bekend is. It Fryske Gea, Olterterp

Jahns S (1996) Vegetation history and climate changes in West Equatorial Africa during the Late Pleistocene and Holocene, based on a marine pollen diagram from the Congo fan. Veg Hist Archaeobot 5:207-213

Jansen P, Wachter WH (1930) Grassen langs de Zuiderzeekust. Ned Kruidkundig Archief 40:231-257

Janzen DH (1984) Dispersal of small seeds by big herbivores: foliage is the fruit. Am Nat 123:338-353

Joenje W (1975) Landschap en plantengroei. In: Abrahamse J, Muntingh H (eds) Noord-Friesland Buitendijks. Landelijke Vereniging tot Behoud van de Waddenzee, Harlingen, pp 24-28

Joenje W (1982) Zeekralen. Waddenbull 17:5-7

Jones GEM (1991) Numerical analysis in archaeobotany. In: Van Zeist W, Wasylikowa K, Behre K-E (eds) Progress in old world palaeoethnobotany. Balkema, Rotterdam, pp 63-80

Jones R (ed, 2012) Manure matters: historical, archaeological and ethnographic perspectives. Ashgate, Farnham

Joosten H, Clarke D (2002) The wise use of mires and peatlands. International Mire Conservation Group and International Peat Society, Jyväskylä

Kalis AJ, Van der Knaap WO, Schweizer A, Urz R (2006) A three thousand year succession of plant communities on a valley bottom in the Vosges Mountains, NE France, reconstructed from fossil pollen, plant macrofossils, and modern phytosociological communities. Veg Hist Archaeobot 15:377-390

Karg S (1998) Winter- and Spring-foddering of Sheep/Goat in the Bronze Age Site of Fiavè-Carera, Northern Italy. Environ Archaeol 1:87-94

Kenward H, Hall A (1997) Enhancing bioarchaeological interpretation using indicator groups: stable manure as a paradigm. J Archaeol Sci 24:663-673

Kleyer M, Bekker RM, Knevel IC, Bakker JP, Thompson K, Sonnenschein M, Posclod P, Van Groenen- dael JM, Klimes L, Klimesová J, Klotz S, Rusch GM, Hermy M, Adriaens D, Boedeltje G, Bossuyt B, Dannemann A, Endels P, Götzenberger L, Hodgson JG, Jackel A-K, Kühn I, Kunzmann D, Ozinga WA, Römermann C, Stadler M, Schlegelmilch J, Steendam HJ, Tackenberg, O, Wilmann B, Cornelisen JHC, Eriksson O, Garnier E, Peco B (2008) The LEDA traitbase: a database of life-history traits of Northwest European flora. J Ecol 96: 1266-1274

KNMI (2011) Maandoverzicht van het weer in Nederland. Juni 2011. Koninklijk Nederlands Meteorologisch Instituut, De Bilt

KNMI (2013) Maandoverzicht van het weer in Nederland. Juni 2013. Koninklijk Nederlands Meteorologisch Instituut, De Bilt

Knol E (1993) De Noord-Nederlandse kustlanden in de Vroege Middeleeuwen. Dissertation, VU University Amsterdam

Knol E, Bardet, AC, Prummel W (eds, 2005) Professor Van Giffen en het geheim van de wierden. Heveskes, Veendam

Knörzer KH (1971) Urgeschichtlicher Unkräuter im Rheinland. Ein Beitrag zur Entstehungsgeschichte der Segetallgesellschaften. Vegetatio 23:89-111

König D (1983) Halligen. Waddenbull 18:185-189

Kooistra LI (1996) Borderland farming. Possibilities and limitations of farming in the Roman Period and Early Middle Ages between the Rhine and Meuse. Dissertation, Leiden University

Kooistra LI (2002a) Pollen en sporen. In: Carmiggelt A, Schulten PJWM (eds) Veldhandleiding archeologie. Archeologie Leidraad 1. College voor de Archeologische Kwaliteit, Zoetermeer, pp 7-12

Kooistra LI (2002b) Botanische macroresten. In: Carmiggelt A, Schulten PJWM (eds) Veldhandleiding archeologie. Archeologie Leidraad 1. College voor de Archeologische Kwaliteit, Zoetermeer, pp 13-18

Kooistra LI, Hänninen K, Van Haaster H, Vermeeren C (1998) Voedselresten in beer en afval. Botanisch onderzoek aan beerputten, afvalkuilen en ophogingslagen van de steden Dordrecht en Nijmegen uit de 12e-20e eeuw (=BIAXiaal 52). BIAX Consult, Zaandam

Kooistra MJ, Kooistra LI, Van Rijn P, Sass-Klaassen U (2006) Woodlands of the past – the excavation of wetland woods at Zwolle-Stadshagen (the Netherlands): reconstruction of the wetland wood in its environmental context. Netherl J Geosci 85:37-60

Kopecký K, Hejný S (1974) A new approach to the classification of anthropogenic plant communities. Vegetatio 29:17-20

Körber-Grohne U (1967) Geobotanische Untersuchungen auf der Feddersen Wierde. Steiner, Wiesbaden

Körber-Grohne U (1979) Bemerkungen zu einer pflanzensoziologischen Zuordnung subfossiler Floren des Postglazials. In: Willmans O, Tüxen R (eds) Werden und Vergehen von Pflanzengesellschaften. Cramer, Vaduz, pp 43-59

Körber-Grohne U (1991) Identification methods. In: Van Zeist W, Wasylikowa K, Behre K-E (eds) Progress in old world Palaeoethnobotany. Balkema,, Rotterdam, pp 3-24

Körber-Grohne U (1992) Studies in salt marsh vegetation and their relevance to the reconstruction of prehistoric plant communities. Rev Palaeobot Palynol 73:167-180

Kreuz A (1995) On-site and off-site data – interpretative tools for a better understanding of Early Neolithic environments. In: Kroll H, Pasternak R (eds) Res Archaeobotanicae. Voges, Kiel

Kreuz A (2005) Landwirtschaft im Umbruch? Archäobotanische Untersuchungen zu den Jahrhunderten um Christi Geburt in Hessen und Mainfranken. Ber RGK 85:97-292

Kreuz A, Schäfer E (2011) Weed finds as indicators for the cultivation regime of the early Neolithic Bandkeramik culture? Veg Hist Archaeobot 20:333-348

Kroll H (1975) Ur- und Frühgeschichtlicher Ackerbau in Archsum auf Sylt. Dissertation, University of Kiel

Kühn M, Maier U, Herbig C, Ismail-Mayer K, Le Bailly M, Wick L (2013) Methods for the examination of cattle, sheep and goat dung in prehistoric wetland settlements with examples of the sites Alleshausen-Täschenwiesen and Alleshausen-Grundwiesen (around cal 2900 BC) at Lake Federsee, south-west Germany. Environ Archaeol 18:43-57

Kuijper WJ (2008) Molluskenonderzoek. In: Nicolay JAW, Dijkstra J (eds) Een terp op de schop. Archeologisch onderzoek op het Oldehoofsterkerkhof te Leeuwarden (=ADC Monografie 3). ADC Archeoprojecten, Amersfoort, pp 38-40

Küster H (1991) Phytosociology and archaeobotany. In: Harris DR, Thomas KD (eds) Modelling ecological change. Perspectives from neoecology, palaeoecology and environmental archaeology. University College London, London, pp 17-26

Lange AG (1988) Plant remains from a native settlement at the Roman frontier: De Horden near Wijk bij Duurstede. Dissertation, University of Groningen

Lenting JJ, Van Malssen N (2011) Een archeologische begeleiding (protocol opgraven) op deelgebied Bogas (Koesteeg/Oostersingel) van het centrumplan Coevorden, gemeente Coevorden (D) (=ARC-Publicaties 224). ARC, Groningen

Lenting JJ, Van Malssen N (eds, 2009) Een archeologische begeleiding (AB) van de aanleg van een 110kV kabelsleuf tussen Eemshaven en Winsum (Gr) (=ARC-Rapporten 2009-43). ARC, Groningen

Lillie M, Ellis S (eds, 2007) Wetland archaeology and environments. Regional issues and global perspectives. Oxbow Books, Oxford

Linseele V, Riemer H, Baeten J, De Vos D, Marinova E, Ottoni C (2013) Species identifications of archaeological dung remains: a critical review of potential methods. Environ Archaeol 18:5-17

Lohof E, Roessingh W (2014) The Westfrisian Bronze Age: a view from Enkhuizen-Kadijken. J Archaeol Low Ctries 5:51-78

Lososova Z, Simonova D (2008) Changes during the 20th century in species composition of synanthropic vegetation in Moravia (Czech Republic). Preslia 80:291-305

Lotter AF (2005) Multi-proxy climatic reconstructions. In: Mackay A, Battarbee R, Birks J, Oldfield F (eds) Global change in the Holocene. Hodder Arnold, London, pp 373-383

Louwe Kooijmans LP (1974) The Rhine/Meuse delta. Four studies on its prehistoric occupation and Holocene geology (=Analecta Praehistoria Leidensia 7). Dissertation, Leiden University

Louwe Kooijmans LP (1985) Sporen in het land. De Nederlandse delta in de prehistorie. Meulenhoff Informatief, Amsterdam

Louwe Kooijmans LP (1993) Wetland exploitation and upland relations of prehistoric communities in the Netherlands. In: Gardiner J (ed) Flatlands and wetlands. Current themes in East Anglian Archaeology (=East Anglian Archaeology 50). Scole Archaeological Committee for East Anglia, Norwich, pp 71-116

Louwe Kooijmans LP (ed, 2001) Archeologie in de Betuweroute. Hardinxveld-Giessendam, De Bruin (=Rapportage Archeologische Monumentenzorg 85). Rijksdienst voor het Oudheidkundig Bodemonderzoek, Amersfoort

Louwe Kooijmans LP (2005) Hunters become farmers. Early Neolithic B and Middle Neolithic A. In: Louwe Kooijmans LP, Van den Broeke PW, Fokkens H, Van Gijn AL (eds) The prehistory of the Netherlands. Amsterdam University Press, Amsterdam, pp 249-271

Lowe JJ, Walker MJC (1997) Reconstructing quaternary environments. Pearson, Harlow

Maier U, Harwath A (2011) Detecting intra-site patterns with systematic sampling strategies. Archaeological grid sampling of the lakeshore settlement Bad Buchau-Torwiesen II, southwest Germany. Veg Hist Archaeobot 20:349-365

Manning A, Birley R, Tipping R (1997) Roman impact on the environment at Hadrian's Wall: precisely dated pollen analysis from Vindolanda, northern England. The Holocene 7:175-186

Marinova E, Linseele V, Kühn M (2013) Bioarchaeological research on animal dung – possibilities and limitations. Environ Archaeol 18:1-3

Marshall EJP, Hopkins A (1990) Plant species composition and dispersal in agricultural land. In: Bunce RGH, Howard DC (eds) Species dispersal in agricultural habitats. Belhaven, London, New York, pp 89-115

Mauquoi D, Van Geel B (2007) Mire and peat macros. In: Elias AE (ed) Encyclopedia of quaternary science. Elsevier, Oxford, pp 2315-2336

Maurer A (2010) Een studie naar de flora bij de terp Anjum-Schanskerwei gedurende de opkomst van bedijking (800–1300 n. Chr.). Bachelor thesis, University of Groningen

Maurer A (2011) Een studie naar de oevervegetatie van de Swifterbantvindplaats S-25 (Oostelijk-Flevoland) (6700–3700 v. Chr.). Master thesis, University of Groningen

Maurer A (2013) Botanisch onderzoek aan de terp Arkum. In: Bakker M (ed) Op het spoor van de vroegste veenontginningen in Westergo. Het archeologisch onderzoek van een nederzetting uit de late ijzertijd en Romeinse tijd bij Arkum, Friesland. Master thesis, University of Groningen

Mcmanus E, Montgomery J, Evans J, Lamb A, Brettell R, Jelsma J (2013) "To the land or to the sea": diet and mobility in Early Medieval Frisia. J Isl Coast Archaeol 8:255-277

Meier D (2004) Man and environment in the marsh area of Schleswig-Holstein from Roman until late Medieval times. Quat Int 112:55-69

Meltzer J, Westhoff V (1942) Inleiding tot de plantensociologie. Breughel, 's Graveland

Menotti F (2012) Wetland archaeology and beyond. Theory and practice. Oxford University Press, Oxford

Menotti F, O'Sullivan A (eds, 2013) The Oxford handbook of wetland archaeology. Oxford University Press, Oxford

Miksicek CH (1987) Formation processes of the archaeobotanical record. In: Schiffer, MB (ed) Advances in archaeological method and theory 10. Academic Press, pp 211-247

Miola A, Favaretto S, Sostizzo I, Valentini G, Asioli A (2010) Holocene salt marsh plant communities in the North Adriatic coastal plain (Italy) as reflected by pollen, non-pollen palynomorphs and plant macrofossil analyses. Veg Hist Archaeobot 19:513-529

Moore PD (1986) Site history. In: Moore PD, Chapman SB (eds) Methods in plant ecology. Blackwell Scientific, London, pp 525-556

Mouissie AM, Lengkeek W, Van Diggelen R (2005a) Estimating adhesive seed-dispersal distances: field experiments and correlated random walks. Func Ecol 19:478-486

Mouissie AM, Van der Veen CEJ, Veen GFC, Van Diggelen R (2005b) Ecological correlates of seed survival after ingestion by fallow deer. Func Ecol 19:284-290

Mulder SA, Ufkes A (2007) Een archeologische opgraving op een afgevlakte terprand te Lutjelollum, gemeente Franekeradeel (Fr.)(=ARC-Publicaties 181). ARC, Groningen

Murphy P, French C (eds, 1988) The exploitation of wetlands (=BAR British Series 186). Archaeopress, Oxford

Nales T (2010) Archeologisch bureauonderzoek en inventariserend veldonderzoek, verkennende fase project rivierduingebied, Swifterbant, Gemeente Dronten (=Becker & Van de Graaf-rapport 951). Becker & Van de Graaf, Noordwijk

Needham S, Macklin MG (eds, 1992) Alluvial archaeology in Britain (=Oxbow Monograph 27). Oxbow Books, Oxford

Neef R, Cappers RTJ, Bekker RM (2012) Digital atlas of economic plants in archaeology (=Groningen Archaeological Studies 17). Barkhuis, Eelde

Neumann K, Kahlheber S, Uebel D (1998) Remains of woody plants from Saouga, a medieval west African village. Veg Hist Archaeobot 7:57-77

Nicolay JAW (ed, 2010a) Terpbewoning in oostelijk Friesland. Twee opgravingen in het voormalige kweldergebied van Oostergo (=Groningen Archaeological Studies 10). Barkhuis, Eelde

Nicolay JAW (2010b) Gedroogde mest. In: Nicolay JAW (ed) Terpbewoning in oostelijk Friesland. Twee opgravingen in het voormalige kweldergebied van Oostergo (=Groningen Archaeological Studies 10). Barkhuis, Eelde, pp 163-165

Nicolay JAW (ed, in prep) Graven aan de voet van de Achlumer dorpsterp. Archeologische sporen rondom een terpnederzetting (=Jaarversl Ver Terpenonderz). Vereniging voor Terpenonderzoek, Groningen

Nicolay JAW, Dijkstra J (eds, 2008) Een terp op de schop. Archeologisch onderzoek op het Oldehoofsterkerkhof te Leeuwarden (=ADC Monografie 3). ADC Archeoprojecten, Amersfoort

Nieuwhof A (2006a) Changing landscape and grazing: macroremains from the terp Peins-east, province of Friesland, the Netherlands. Veg Hist Archaeobot 15:125-136

Nieuwhof A (2006b) De wierde Wierum (provincie Groningen). Een archeologisch steilkantonderzoek (=Groningen Archaeological Studies 3). Barkhuis, Eelde

Nieuwhof A (ed, 2008a) De Leege Wier van Englum. Archeologisch onderzoek in het Reitdiepgebied (=Berichten van de Vereniging voor Terpenonderzoek 91). Vereniging van Terpenonderzoek, Groningen

Nieuwhof A (2008b) 14C-dateringen en stabiele isotopen. In: Nieuwhof A (ed) De Leege Wier van Englum. Archeologisch onderzoek in het Reitdiepgebied (=Berichten van de Vereniging voor Terpenonderzoek 91). Vereniging van Terpenonderzoek, Groningen, pp 249-254

Nieuwhof A (2012) Macrobotanische resten in de terp Peins-Oost. Een onderzoek naar natuurlijke en antropogene vegetaties en vroege landbouw (=Grondsporen 11). Groningen Institute of Archaeology, Groningen

Nieuwhof A (2013) Anglo-Saxon immigration or continuity? Ezinge and the coastal area of the northern Netherlands in the Migration Period. J Archaeol Low Ctries 4:53-84

Nieuwhof A, Jöns H, De Langen G, Nicolay J, Siegmüller A (2013) Leven met de zee: terpen, wierden en wurten (Leben mit dem Meer: Terpen, Wierden und Wurten). In: Kegler JF (ed) Land van ontdekkingen. De archeologie van het Friese kustgebied (Land der Entdeckungen. Die Archäologie des friesischen Küstenraums). Ostfriesischen Landschaftliche Verlags- und Vertriebsgesellschaft, Aurich, pp 147-155

Nieuwhof A, Woldring H (2008) Botanische resten. In: Nieuwhof A (ed) De Leege Wier van Englum. Archeologisch onderzoek in het Reitdiepgebied (=Berichten van de Vereniging voor Terpenonderzoek 91). Vereniging van Terpenonderzoek, Groningen, pp 160-176

O'Connor T (1988) Slums puddles and ditches: are molluscs useful indicators? In: Murphy P, French C (eds) The exploitation of wetlands. BAR, Oxford, pp 61-68

Oldfield F (2005) Introduction: the Holocene, a special time. In: Mackay A, Battarbee R, Birks J, Oldfield F (eds) Global change in the Holocene. Hodder Arnold, London, pp 1-9

Oost AP, Hoekstra P, Wiersma A, Flemming B, Lammerts EJ, Pejrup M, Hofstede J, Van der Valk B, Kiden P, Bartholdy J, Van den Berg MW, De Vries S, Wang ZB (2012) Barrier island management: lessons from the past and directions for the future. Ocean Coast Manag 68:18-38

Out WA (2008) Growing habits: delayed introduction of crop cultivation at marginal Neolithic wetland sites. Veg Hist Archaeobot 17:131-138

Out WA (2009a) Sowing the seed? Human impact and plant subsistence in Dutch wetlands during the Late Mesolithic and Middle Neolithic (5500–4300 cal BC)(=Archaeological Studies Leiden University 18). Dissertation, Leiden University

Out WA (2009b) Reaction to "Cereal cultivation at Swifterbant? Neolithic wetland farming on the North European Plain". Curr Anthropol 50:253-254

Out WA (2010a) Firewood collection strategies at Dutch wetland sites in the process of Neolithisation. The Holocene 20:191-204

Out WA (2010b) Hout. In: Tuinstra SJ, Van Malssen N (eds) Een archeologische opgraving op de locatie van twee archeologische monumenten aan het Oude Diep tussen Goutum en Wirdum, gemeente Leeuwarden (Fr) (=ARC-Publicaties 210). ARC, Groningen, pp 95-103

Out WA (2012) What's in a hearth? Seeds and fruits from the Neolithic fishing and fowling camp at Bergschenhoek, the Netherlands, in a wider context. Veg Hist Archaeobot 21:201-214

Out WA, Kaaijk S (2010) Botanische macroresten. In: Tuinstra SJ, Van Malssen N (eds) Een archeologische opgraving op de locatie van twee archeologische monumenten aan het Oude Diep tussen Goutum en Wirdum, gemeente Leeuwarden (Fr) (=ARC-Publicaties 210). ARC, Groningen, pp 105-109

Out WA, Schepers M (2011) Botanische macroresten. In: Lenting JJ, Van Malssen N (eds) Een archeologische begeleiding (protocol opgraven) op deelgebied Bogas (Koesteeg/Oostersingel) van het centrumplan Coevorden, gemeente Coevorden (D) (=ARC-Publicaties 224). ARC, Groningen, pp 71-74

Out WA, Vermeeren C, Hänninen K (2013) Branch age and diameter: useful criteria for recognising woodland management in the present and the past? J Archaeol Sci 40:4083-4097

Overpeck JT, Webb T III, Prentice IC (1985) Quantitative interpretation of fossil pollen spectra. Dissimilarity coefficients and the method of modern analogs. Quaternar Res 23:87-108

Pals JP (1999) Preliminary notes on crop plants and the natural and anthropogeneous vegetation. In: Besteman JC, Bos JM, Gerrets DA, Heidinga HA, De Koning J (eds) The excavations at Wijnaldum. Reports on Frisia in Roman and Medieval times. Balkema, Rotterdam, pp 139-149

Pals JP, Van Dierendonck MC (1988) Between flax and fabric: cultivation and processing of flax in a medieaeval peat reclamation settlement near Midwoud (Prov. Noord-Holland). J Archaeol Sci 15:237-251

Peeters H, Hogestijn W-J, Holleman T (2004) De Swifterbantcultuur. Een nieuwe kijk op de aanloop naar de voedselproductie. Uniepers, Abcoude

Peeters JHM (2007) Hoge Vaart-A27 in context: towards a model of Mesolithic–Neolithic land use dynamics as a framework for archaeological heritage management. Dissertation, University of Amsterdam

Postma D (2010) ···En zulks is de relatie tussen schoonheid en wanstaltigheid. De toepassingsmogelijkheden van zoden aan de hand van archeologische, historische en etnografische voorbeelden. Jaarversl Ver Terpenonderz 93:11-34

Pott R (1992) Die Pflanzengesellschaften Deutschlands. Ulmer, Stuttgart

Prummel W, Raemaekers DCM, Beckerman SM, Bottema-Mac Gillavry JN, Cappers RTJ, Cleveringa P (2009) Terug naar Swifterbant: een kleinschalige opgraving te Swifterbant-S2 (Gemeente Dronten). Archeologie 13:17-45

Prummel W, Van Gent J (2010) Dieren van de middeleeuwse terp Anjum-Terpsterweg. In: Nicolay JAW (ed) Terpbewoning in oostelijk Friesland. Twee opgravingen in het voormalige kweldergebied van Oostergo (=Groningen Archaeological Studies 10). Barkhuis, Eelde, pp 249-268

Purdy BA (2001) Enduring records. The environmental and cultural heritage of wetlands. Oxbow Books, Oxford

Raemaekers DCM (1999) The Articulation of a "New Neolithic": the meaning of the Swifterbant culture for the process of Neolithisation in the western part of the North European Plain (4900-3400 BC)(=Archaeological Studies Leiden University 3). Dissertation, Leiden University

Raemaekers DCM (2005) Het Vroeg- en Midden-Neolithicum in Noord-, Midden, en West-Nederland. In: Deeben J, Drenth E, Van Oorsouw M-F, Verhart L (eds) De steentijd van Nederland (=Archeologie 11/12). Stichting Archeologie, pp 261-282

Raemaekers DCM (ed, in prep.a) Swifterbant S4: the excavation of the Neolithic river bank site Swifterbant S4 (=Groningen Archaeological Studies). Barkhuis, Eelde

Raemaekers DCM (ed, in prep.b) Standaardrapportage Swifterbant S25. Groningen (=Groningen Archaeological Studies). Barkhuis, Eelde

Raemaekers DCM, Devriendt I, Cappers RTJ, Prummel W (2005) Het nieuwe Swifterbant project: nieuw onderzoek aan de Mesolithische en Neolithische vindplaatsen nabij Swifterbant (provincie Flevoland, Nederland). Notae Praehistorica 25:119-127

Regnell M, Gaillard M-J, Bartholin TS, Karsten P (1995) Reconstruction of environment and history of plant use during the late Mesolithic (Ertebølle culture) at the inland settlement of Bökeberg III, southern Sweden. Veg Hist Archaeobot 4:67-91

Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE, Burr GS, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Hajdas TP, Heaton TJ, Hogg AG, Hughen KA, Kaiser KF, Kromer B, McCormac FG, Manning SW, Reimer RW, Richards DA, Southon JR, Talamo S, Turney CSM, Van der Plicht J, Weyhenmeyer CE (2009) IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. Radiocarbon 51(4):1111-1150

Rintjema S, Claassen THL, Hettema H, Hosper UG, Wymenga E (2001) De Alde Feanen: schets van een laagveenmoeras. It Fryske Gea, Leeuwarden

Rippon S (2000) The transformation of coastal wetlands. Exploitation and management of marshland landscapes in North West Europe during the Roman and medieval periods. Oxford University Press, Oxford

Robinson M (1992) Environment, archaeology and alluvium on the river gravels of the South Midlands. In: Needham S, Macklin MG (eds) Alluvial archaeology in Britain (=Oxbow Monograph 27). Oxbow Books, Oxford, pp 197-208

Rodwell JS (ed, 1998a) British plant communities. Volume 1. Woodlands and scrub. Cambridge University Press, Cambridge

Rodwell JS (ed, 1998b) British plant communities. Volume 2. Mires and heaths. Cambridge University Press, Cambridge

Rodwell JS (ed, 1998c) British plant communities. Volume 3. Grasslands and montane communities. Cambridge University Press, Cambridge

Rodwell JS (ed, 1998d) British plant communities. Volume 4. Aquatic communitites, swamps and tall-herb fens. Cambridge University Press, Cambridge

Rodwell JS (ed, 2000) British plant communities. Volume 5. Maritime communities and vegetation of open habitats. Cambridge University Press, Cambridge

Roeleveld W (1974) The Groningen coastal area. A study in Holocene geology and lowland physical geography. Dissertation, VU University Amsterdam

Rösch M (1996) New approaches to prehistoric land-use reconstruction in south-western Germany. Veg Hist Archaeobot 5:65-79

Runhaar J, Van Landuyt W, Groen CLG, Weeda EJ, Verloove F (2004) Herziening van de indeling in ecologische soortengroepen voor Nederland en Vlaanderen. Gorteria 30/1:12-26

Sallon S, Solowey E, Cohen Y, Korchinsky R, Egli M, Woodhatch I, Simchoni O, Kislev M (2008) Germination, genetics, and growth af an ancient date seed. Sci 320:1464

Schaminée JHJ, Jansen JAM (2012) Geboeid door het verleden. Beschouwingen over historische ecologie. KNNV, Zeist

Schaminée JHJ, Stortelder AHF, Weeda EJ (1996) De vegetatie van Nederland. Volume 3. Opulus, Uppsala

Schaminée JHJ, Stortelder AHF, Westhoff V (1995a) De vegetatie van Nederland. Volume 1. Opulus, Uppsala

Schaminée JHJ, Stortelder AHF, Westhoff V (1995b) De synthetische fase van het vegetatieonder-zoek. In: Schaminée JHJ, Stortelder AHF, Westhoff V (eds) De vegetatie van Nederland. Volume 1. Opulus, Uppsala, pp 15-32

Schaminée JHJ, Sýkora K, Smits N, Horsthuis M (2010) Veldgids plantengemeenschappen van Nederland. KNNV, Zeist

Schaminée JHJ, Weeda EJ (2009) Natuur als nooit tevoren. Beschouwingen over natuurbeheer in Nederland. KNNV, Zeist

Schaminée JHJ, Weeda EJ, Westhoff V (1995c) De vegetatie van Nederland. Volume 2. Opulus, Uppsala

Schaminée JHJ, Weeda EJ, Westhoff V (1998) De vegetatie van Nederland. Volume 4. Opulus, Uppsala

Schepers M (2010) Botanische macroresten. In: Lenting JJ, Van Malssen N (eds) Een archeologische begeleiding (AB) van de aanleg van een 110kV kabelsleuf tussen Eemshaven en Winsum (Gr) (=ARC-Rapporten 2009-43). ARC, Groningen, pp 12-13

Schepers M (2011) Botanische macroresten. In: Lenting JJ (ed) Archeologisch onderzoek naar het Magazijn van Oorlog aan de Oudeschans 2 te Delfzijl (Gr)(=ARC-Publicaties 214). ARC, Groningen, pp 135-139

Schepers M (2012a) Bodemmicromorfologisch onderzoek. In: Van Benthem A (ed) Haak om Leeuwarden. Vindplaats 1, Marssum It Aldlân (=ADC rapport 2523). ADC Archeoprojecten, Amersfoort, pp 75-79

Schepers M (2012b) Botanische macroresten. In: Ufkes A, Tuinstra SJ (eds) Een archeologisch inventariserend veldonderzoek (IVO) en een archeologische opgraving van een vroegmiddeleeuwse terp bij de afrit 'Akkerwinde' te Sneek, gemeente Sneek (Fr.) (=ARC-publicaties 191). ARC, Groningen, pp 105-109

Schepers M (2012c) Botanische macroresten. In: Tuinstra SJ (ed) Een archeologisch inventariserend veldonderzoek (IVO) door middel van een proefsleuf op locatie It Fliet te Witmarsum, gemeente Wûnseradiel (F) (=ARC-Publicaties 240). ARC, Groningen, pp 41-42

Schepers M (in prep) Zilt met een korreltje zout. Nieuw licht op vegetatie rond de terp. In: Nicolay JAW (ed) Graven aan de voet van de Achlumer dorpsterp. Archeologische sporen rondom een terpnederzetting (=Jaarversl Ver Terpenonderz). Vereniging voor Terpenonderzoek, Groningen

Schepers M (2014) Wet, wealthy worlds: the environment of the Swifterbant river system during the Neolithic occupation (4300–4000 cal BC). J Archaeol Low Ctries 5:79-105

Schepers M, Cappers RTJ, Bekker RM (2013a) A review of prehistoric and early historic mainland salt marsh vegetation in the northern-Netherlands based on the analysis of plant macrofossils. J Coast Conserv 17:755-773

Schepers M, Scheepens JF, Cappers RTJ, Van Tongeren OFR, Raemaekers DCM, Bekker RM (2013b) An objective method based on assemblages of subfossil plant macro-remains to reconstruct past natural vegetation: a case study at Swifterbant, the Netherlands. Veg Hist Archaeobot 22:243-255

Schepers M, Bottema-Mac Gillavry N (in prep) Archaeobotanical remains. In: Raemaekers DCM (ed) The excavation of the Neolithic river bank site Swifterbant S4 (=Groningen Archaeological Studies). Barkhuis, Eelde

Schepers M, Woltinge I (in prep) Landscape development and stratigraphy. In: Raemaekers DCM (ed) Swifterbant S4: the excavation of the Neolithic river bank site Swifterbant S4 (=Groningen Archaeological Studies). Barkhuis, Eelde

Schlumbaum A, Tensen M, Jaenicke-Després V (2008) Ancient plant DNA in archaeobotany. Veg Hist Archaeobot 17:233-244

Schoute JFTh (1984) Vegetation horizons and related phenomena. A palaeoecological-micromorphological study in the younger coastal Holocene of the northern Netherlands (Schildmeer area). Dissertation, VU University Amsterdam

Shahack-Gross R (2011) Herbivorous livestock dung: formation, taphonomy, methods for identification, and archaeological significance. J Archaeol Sci 38:205-218

Shepherd KA, Macfarlane TD, Colmer TD (2005) Morphology, anatomy and histochemistry of Salicornioideae (Chenopodiaceae) fruits and seeds. Ann Bot 95:917-933

Sissingh G (1950) Onkruid-associaties in Nederland. Dissertation, Wageningen University

Smith DN, Roseff R, Butler S (2001) The sediments, pollen plant macro-fossils and insects from a Bronze Age channel fill at Yoxall Bridge, Staffordshire. Environ Archaeol 6:1-12

Smits L, Van der Plicht H (2009) Mesolithic and Neolithic human remains in the Netherlands: physical anthropological and stable isotope investigations. J Archaeol Low Ctries 1:55-85

Sorensen AE (1986) Seed dispersal by adhesion. Ann Rev Ecol Syst 17:443-463

Stiles EW (1980) Patterns of fruit presentation and seed dispersal in bird-disseminated woody plants in the Eastern deciduous Forest. Am Nat 116:670-688

Stock M (2011) Patterns in surface elevation change across a temperate salt marsh platform in relation to sea-level rise. In: Karius V, Hadler H, Deicke M, Von Eynatten H, Brückner H, Vött A (eds) Dynamische Küsten – Grundlagen, Zusammenhänge und Auswirkungen (=Coastline Reports 17). Die Küsten Union Deutschland, Rostock, pp 33-47

Stortelder AHF, Schaminée JHJ, Hommel PWFM (1999) De vegetatie van Nederland. Volume 5. Opulus, Uppsala

Stroh PA, Owen Mountford J, Hughes FMR (2012) The potential for endozoochorous dispersal of temperate fen plant species by free-roaming horses. Appl Veg Sci 15:359-368

Sugita S (1994) Pollen representation of vegetation in Quaternary sediments: theory and method in patchy vegetation. J Ecol 82:881-897

Sukopp H (1969) Der Einfluss des Menschen auf die Vegetation. Vegetatio 17:360-371

Swertz CA, Weeda EJ, Stortelder AHF (1999) Epilobietea angustifolii. In: Stortelder AFH, Schaminée JHJ, Hommel PWFM (eds) De vegetatie van Nederland. Volume 5. Opulus, Uppsala, pp 73-88

Tamis WLM, Van der Meijden R, Runhaar J, Bekker RM, Ozinga, WA Odé B, Hoste I (2004) Standaardlijst van de Nederlandse Flora 2003. Gorteria 30:101-195

Ten Anscher TJ (2012) Leven met de Vecht: Schokland-P14 en de Noordoostpolder in het neolithicum en de bronstijd. Dissertation, University of Amsterdam

Ter Braak CJF, Šmilauer P (2002) CANOCO reference manual and CanoDraw for Windows user's guide: software for canonical community ordination (version 4.5). Microcomputer Power, Ithaca, New York

Thasing S, Van Klink R, Schepers M, Cappers RTJ, Brüning EBE (2012) Kevers en hun potentie voor onderzoek in het terpengebied. Paleo-aktueel 23:111-118

Thompson K, Bakker JP, Bakker RM (1997) The soil seed banks of north west Europe: methodology, density and longevity. Cambridge University Press, Cambridge

Thompson K, Grime JP (1979) Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. J Ecol 67:893-921

Tolar T, Jacomet S, Veluščcek A, Čufar K (2010) Recovery techniques for waterlogged archaeological sediments: a comparison of different treatment methods for samples from Neolithic lake shore settlements.Veg Hist Archaeobot 19:53-67

Tomlinson P (1985) An aid to the identification of fossil buds, bud-scales and catkin-bracts of British trees and shrubs. Circaea 3:45-130

Tuinstra SJ, Van Malssen N (eds, 2010) Een archeologische opgraving op de locatie van twee archeologische monumenten aan het Oude Diep tussen Goutum en Wirdum, gemeente Leeuwarden (Fr) (=ARC-Publicaties 210). ARC, Groningen

Van Asselen S, Bos I (2009) Veen in de Rijn-Maas delta: groei, afbraak en compactie. Grondboor en Hamer 3/4:54-61

Van Benthem A (ed, 2012) Haak om Leeuwarden. Vindplaats 1, Marssum It Aldlân (=ADC rapport 2523). ADC Archeoprojecten, Amersfoort

Van Beurden L (2008) Vegetatie en ontwikkelingen in het rivierengebied in de Bronstijd (=BIAXiaal 331). BIAX Consult, Zaandam

Van de Plassche O, Bohncke SJP, Makaske B, Van der Plicht J (2005) Water-level; changes in the Flevo area, central Netherlands (5300-1500 BC): implications for relative mean sea-level rise in the Western Netherlands. Quaternar Int 133-134:77-93

Van den Berg M, Huisman H, Kars, H, Van Haaster H, Kool J (2010) Assessing in situ preservation of archaeological wetland sites by chemical analysis of botanical remains and micromorphology. In: Bloemers T, Kars, H, Van der Valk A, Wijnen M (eds) The cultural landscape and heritage paradox. Amsterdam University Press, Amsterdam, pp 161-176

Van den Bos V, Brinkkemper O, Bull ID, Engels S, Hakbijl T, Schepers M, Van Dinter M, Van Reenen G, Van Geel B (2014) Roman impact on the landscape near castellum Fectio, the Netherlands. Veg Hist Archaeobot 23:277-298

Van der Laan J (2011) "Uit het goede hout gesneden": een materiaalonderzoek aan het nat-geconserveerde hout van Swifterbant vindplaats S25. Bachelors thesis, University of Groningen

Van der Laan J (2013a) Akkerbouw langs de Middelzee. Archeobotanisch onderzoek naar de macroresten uit enkele akkerlagen van de terp Jelsum. Unpublished student report, University of Groningen

Van der Laan J (2013b) Terpbewoners op eigen houtje? Archeobotanisch onderzoek naar houtgebruik op de terpen in het Noord-Nederlands kustgebied tussen 600 v. Chr. en 1200 n. Chr. Master thesis, University of Groningen

Van der Linden M (2008) Mesolithische en Vroeg-Neolithische bewoningssporen bij Swifterbant. Pollenonderzoek op vindplaats 5 in het kader van de aanleg van de N23 tussen Lelystad en Dronten (=BIAXiaal 365). BIAX Consult, Zaandam

Van der Meijden R (2005) Heukels' Flora van Nederland. Wolters-Noordhoff, Groningen/Houten

Van der Veen M (2007) Formation processes of dessicated and carbonized plant remains – the identification of routine practice. J Archaeol Sci 34:968-990

Van der Veen M, Fieller N (1982) Sampling seeds. J Archaeol Sci 9(3):287-298

Van der Veen Y (2008) Palynologisch onderzoek aan de akker van Swifterbant S4. Unpublished student report, University of Groningen

Van der Waals JD (1977) Excavations at the natural levee sites S2, S3/5 and S4. Helinium 17:3-27

Van der Waals JD, Waterbolk HT (1976) Excavations at Swifterbant – discovery, progress, aims and methods. Helinium 16:4-14

Van der Woude JD (1983) Holocene paleoenvironmental evolution of a perimarine fluviatile area (=Analecta Praehistorica Leidensia 16). Dissertation, VU University Amsterdam

Van Dijk J, Bouman MTIJ, Moolhuizen C, Bos JAA (2011) De voedseleconomie vanaf de Midden-IJzertijd tot en met de Late Middeleeuwen. In: Dijkstra J, Zuidhoff FS (eds) Kansen op de kwelder (=ADC Monografie 10). ADC Archaeoprojecten, Amersfoort, pp 109-130

Van Dinter M (2013) The Roman Limes in the Netherlands: how a delta landscape determined the location of the military structures. Neth J Geosci 92:11-32

Van Geel B (1978) A palaeoecological study of Holocene peat bog sections in Germany and the Netherlands, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals. Rev Palaeobot Palynol 25:1-20

Van Geel B, Buurman J, Brinkkemper O, Schelvis J, Aptroot A, Van Reenen G, Hakbijl T (2003) Environmental reconstruction of a Roman Period settlement site in Uitgeest (the Netherlands), with special reference to coprophilous fungi. J Archaeol Sci 30:873-883

Van Giffen AE (1932) Mededeeling omtrent het systematisch onderzoek, verricht in de jaren 1928, 1929 en 1930. Jaarversl Ver Terpenonderz 13-15:16-46

Van Gijn AL, Waterbolk HT (1984) The colonization of the salt marshes of Friesland and Groningen: the possibilities of a transhumant prelude. Palaeohist 26:101-122

Van Ginkel E, Verhart L (2009) Onder onze voeten. De archeologie van Nederland. Bert Bakker, Amsterdam

Van Goor ACJ (1922) De halophyten en submerse phanerogamen. In: Redeke HC (ed) Flora en fauna der Zuiderzee: monografie van een brakwatergebied. Nederlandsche Dierkundige Vereeniging, Den Helder, pp 47-53

Van Haaster H (2003) Op zoek naar de voedingsgewoonten van de familie Van Arkel. Een botanisch onderzoek een de inhoud van enkele beerputten (=BIAXiaal 270). BIAX Consult, Zaandam

Van Haaster H (2005) Voedingsgewoonten en milieuomstandigheden op en rond twee nederzettingen uit de 12e/13e eeuw te Beetgumermolen (Fr.)(=BIAXiaal 229). BIAX Consult, Zaandam

Van Haaster H (2006a) Voedingsgewoonten en milieuomstandigheden op en rond een vroeg-middeleeuwse nederzetting bij Tzummarum (Fr.)(=BIAXiaal 281). BIAX Consult, Zaandam

Van Haaster H (2006b) Voedingsgewoonten en milieuomstandigheden op en rond een middeleeuwse vindplaats aan de Kimswerderlaan bij Zürich (Fr.) alsmede enkele archeobotanische waarnemingen op de locatie Hegewiersterfjild (=BIAXiaal 282). BIAX Consult, Zaandam

Van Haaster H (2007) Archeobotanisch onderzoek aan de Maasboulevard in Venlo (=BIAXiaal 270). BIAX Consult, Zaandam

Van Haaster H (2008) Archaeobotanica uit 's-Hertogenbosch (=Groningen Archaeological Studies 6). Dissertation, University of Amsterdam

Van Haaster H, Brinkhuizen D, Van Rijn P, Zeiler JT (2003) Plantaardige en dierlijke resten uit enkele 13e-eeuwse ophogingslagen in Dokkum (=BIAXiaal 153). BIAX Consult, Zaandam

Van Haaster H, Brinkkemper O (1995) RADAR, a relational archaeobotanical database for advanced research. Veg Hist Archaeobot 4:117-125

Van Rooij JAG (2007) Botanische resten uit Swifterbant S4. Unpublished student report, University of Groningen

Van Smeerdijk D, Pals JP, Van Geel B, Van Bennekom J (2009) Mens en landschap in middeleeuws Diemen. In: Blok H, Krook W, Van Reenen P (eds) Diemen in het land van Amstel. De Bataafsche Leeuw, Amsterdam, pp 351-366

Van 't Veer R, Van Geel B, Pals JP, Van Smeerdijk D (2000) Fossiele plantengemeenschappen als referentie voor moderne moerasontwikkeling. In: Schaminée JHJ, Van 't Veer R (eds) 100 jaar op de knieën. De geschiedenis van de plantensociologie in Nederland. Opulus, Noordwolde, pp 174-189

Van Tongeren O, Gremmen N, Hennekens S (2008) Assignment of relevées to pre-defined classes by supervised clustering of plant communities using a new composite index. J Veg Sci 19:525-536

Van Vilsteren VT (1984) The medieval village of Dommelen: a case study for the interpretation of charred seeds from postholes. In: Van Zeist W, Casparie WA (eds) Plants and ancient man. Balkema, Rotterdam, pp 227-235

Van Zeist W (1955) Pollen analytical investigations in the northern Netherlands with special reference to archaeology. Dissertation, Utrecht University

Van Zeist W (1974) Palaeobotanical studies of settlement sites in the coastal area of the Netherlands. Palaeohist 16:223-371

Van Zeist W (1988a) Archeobotanisch onderzoek van Oldeboorn. In: Bierma M, Clason AT, Kramer E, De Langen GJ (eds) Terpen en wierden in het Fries-Groningse kustgebied. Wolters-Noordhoff/Forsten, Groningen, pp 190-195

Van Zeist W (1988b) Botanical evidence of relations between the sand and clay districts of the north of the Netherlands in medieval times. In: Küster H (ed) Der prähistorische Mensch und seine Umwelt. Festschrift für Udelgard Körber-Grohne. Konrad Theiss, Stuttgart, pp 381-387

Van Zeist W (1989) Plant remains from a Middle Iron Age coastal marsh site near Middelstum. An intriguing cereal grain find. Helinium 28:103-116

Van Zeist W, Cappers RTJ, Neef R, During H (1987) A palaeobotanical investigation of medieval occupation deposits in Leeuwarden, the Netherlands. Proc K Ned Akad Wet 90:371-426

Van Zeist W, Palfenier-Vegter RM (1981) Seeds and fruits from the Swifterbant S3 site. Final reports on Swifterbant IV. Palaeohist 23:105-168

Van Zeist W, Van Hoorn TC, Bottema S, Woldring H (1976) An agricultural experiment in the unprotected salt marsh. Palaeohist 18:111-153

Vandenbussche V, T'Jollyn F, Zwaenepoel A, Van den Balck E, Hoffman M (2002) Systematiek van natuur-typen voor Vlaanderen: 12. Slik en Schor. Instituut voor Natuurbehoud, Brussel

Veeneklaas RM, Dijkema KS, Hecker N, Bakker JP (2013) Spatio-temporal dynamics on the invasive plant species Elytrigia atherica on natural salt marshes. Appl Veg Sci 16:205-216

Verbruggen F (2012) Archeobotanisch onderzoek. In: Van Benthem A (ed) Haak om Leeuwarden. Vindplaats 1, Marssum It Aldlân (=ADC rapport 2523). ADC Archeoprojecten, Amersfoort, pp 42-53

Verhoeven J, Van Vierssen W, Janssen Duijghuijzen G, Scheperboer G (1978) Flora en fauna in de brakke ringdobben op de Friese kwelder. Waddenbull 13:576-572

Vermue AF (2012) Noordbroek. Een interdisciplinair onderzoek naar de vorming en ingebruikname van de kleilanden in de 15e en 16e eeuw. Master thesis, University of Groningen

Visscher J (1949) Veenvorming. J. Noorduijn en Zoon, Gorinchem

Vissinga A (2007) Swifterbant (Fl.) – Noordertocht H37: een inventariserend archeologisch veldonderzoek (=Steekproefrapport 2007-05/07). De Steekproef, Zuidhorn

Vos P, Kiden P (2005) De landschapsvorming tijdens de steentijd. In: Deeben J, Drenth E, Van Oorsouw M-F, Verhart L (eds) De steentijd van Nederland (=Archeologie 11-12). Stichting Archeologie, Zutphen, pp 7-37

Vos PC (1999) The subatlantic evolution of the coastal area around the Wijnaldum-Tjitsma terp. In: Besteman JC, Bos JM, Gerrets DA, Heidinga HA, De Koning J (eds) The excavations at Wijnaldum. Reports on Frisia in Roman and Medieval times. Balkema, Rotterdam, pp 33-72

Vos PC, De Wolf H (1988) Methodological aspects of palaeoecological research in coastal areas of the Netherlands. Geol Mijnb 67:31-40

Vos PC, Knol E (2005) Wierden ontstaan in een dynamisch getijdenlandschap. In: Knol E, Bardet AC, Prummel W (ed) Professor van Giffen en het geheim van de wierden. Heveskes/Groninger Museum, Veendam/ Groningen, pp 118-135

Vrede F, Dopmeyer HG, Kortmann FJMB, Valk A (2010) De cultuurgewassen en wilde planten. In: Huis in 't Veld J (ed) Wonen op een huiswierde in de Late Middeleeuwen en Nieuwe Tijd. Archeologisch onderzoek in de toekomstige nieuwbouwwijk de held III te Groningen (=Stadse Fratsen 22). Stichting Monument en Materiaal/Gemeente Groningen, Dienst RO/EZ, Groningen, pp 81-84

Wallace M, Charles M (2013) What goes in does not always come out: the impact of the ruminant digestive system of sheep on plant material, and its importance for the interpretation of dung-derived archaeobotanical assemblages. Environ Archaeol 18:18-30

Waterbolk HT (1954) De praehistorische mens en zijn milieu. Dissertation, University of Groningen

Weeda EJ, Haveman R, Schaminée JHJ (2003) Veranderingen in de samenstelling van akkerassociaties (Stellarietea mediae). Stratiotes 26:20-52

Weeda EJ, Schaminée JHJ, Stortelder AFH (1999) Galio-Urticetea. In: Stortelder AHF, Schaminée JHJ, Hommel PWFM (eds) De vegetatie van Nederland. Volume 5. Opulus, Uppsala, pp 41-72

Weeda EJ, Van 't Veer R, Schaminée JHJ (1998) Bidentetea tripartitae. In: Schaminée JHJ, Weeda EJ, Westhoff V (eds) De vegetatie van Nederland. Volume 4. Opulus, Uppsala, pp 173-198

Weeda EJ, Westra R, Westra Ch, Westra T (2003) Nederlandse oecologische flora: wilde planten en hun relaties 5. KNNV, Amsterdam

Weijdema F, Brinkkemper O, Peeters H, Van Geel B (2011) Early Neolithic human impact on the vegetation in a wetland environment in the Noordoostpolder, central Netherlands. J Archaeol Low Ctries 3:31-46

Wells FH, Lauenroth WK (2007) The potential for horses to disperse alien plants along recreational trails. Rangel Ecol Manag 60:574-577

West CF (2013) Islands, coastlines, and stable isotopes: advances in archaeology and geochemistry. J Isl Coastal Archaeol 8:149-151

Westerhoff R (1871) Over boonen, vlas en haver uit onze terpen of wierden. Een eerste kleine bijdrage tot de flora dezer merkwaardige heuvelen. Bijdr Geschied Oudheidkd Inzonderheid Prov Groningen 8:318-331

Westhoff V, Stortelder AHF, Grootjans AP (1995) Vegetatie als object van onderzoek. In: Schaminée JHJ, Stortelder AHF, Westhoff V (eds) De vegetatie van Nederland 1. Opulus, Uppsala, pp 15-32

Westhoff V, Van der Maarel E (1978) The Braun-Blanquet approach. In: Whittaker RH (ed) Classification of plant communities. Junk, The Hague, pp 287-399

Wetzel RG (2001) Limnology: lake and river ecosystems. Academic Press, San Diego

Wheeler BD, Proctor MCF (2000) Ecological gradients, subdivisions and terminology of north-west European mires. J Ecol 88:187-203

Wiersma AP, Oost AP, Van den Berg MW, Vos PC, Marges V, De Vries S (2009) Geomorphology. Thematic Report 9. In: Marencic H, De Vlas J (eds) Quality status report 2009 (=Wadden Sea Ecosystem No. 25). Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven

Willemsen J, Van 't Veer R, Van Geel B (1996) Environmental change during the medieval reclamation of the raised-bog area Waterland (the Netherlands): a palaeophytosociological approach. Rev Palaeobot Palynol 94:75-100

Willerding U (1979) Paläo-Ethnobotanische Untersuchungen über die Entwicklung von Pflanzengesellschaften. In: Willmans O, Tüxen R (eds) Werden und Vergehen von Pflanzengesellschaften. Cramer, Vaduz, pp 61-109

Willerding U (1991) Präsenz, Erhaltung und Repräsentanz von Pflanzenresten in archäologischem Fundgut. In: Van Zeist W, Wasylikowa K, Behre K-E (eds) Progress in old world palaeoethnobotany. Balkema, Rotterdam, pp 25-51

Wilson DG (1984) The carbonisation of weed seeds and their representation in macrofossil assemblages. In: Van Zeist W, Casparie WA (eds) Plants and ancient man. Balkema, Rotterdam, pp 201-206

Woldring H, Kleine E (2008) Pollenanalyse van de mestlagen: aanwijzingen van de intensivering van de begrazing in de Romeinse tijd. In: Nicolay JAW, Dijkstra J (eds) Een terp op de schop. Archeologisch onderzoek op het Oldehoofsterkerkhof te Leeuwarden (=ADC Monografie 3). ADC Archeoprojecten, Amersfoort, pp 259-267

Wolters M, Bakker JP (2002) Soil seed bank and driftline composition along a successional gradient on a temperate salt marsh. Appl Veg Sci 5:55-62

Yashina S, Gubin S, Maksimovich S, Yashina A, Gakhova E, Gilichinsky D (2012) Regeneration of whole fertile plants from 30,000-y-old fruit tissue buried in Siberian permafrost. Proc Natl Acad Sci 109:4008-4013

Zagwijn WH (1994) Reconstruction of climate change during the Holocene in western and central Europe based on pollen records of indicator species. Veg Hist Archaeobot 3:65-88

Zeiler JT (1986) Swifterbant: dwelling place for a season or throughout the whole year? An archaeozoological contribution. In: Fokkens H, Banga P, Bierma M (eds) Op zoek naar mens en materiële cultuur. University of Groningen, Groningen, pp 85-95

Zeiler JT (1997) Hunting, fowling and stock-breeding at Neolithic sites in the western and central Netherlands, Dissertation, University of Groningen

Samenvatting

Het reconstrueren van vroegere vegetatie is altijd al *één* van de hoofddoelen geweest in de archeobotanie. Het detail waarin deze reconstructie uitgevoerd wordt, is voor een belangrijk deel afhankelijk van de geografische en chronologische omvang van de studie. Een studie naar de vegetatieontwikkeling in Noordwest-Europa gedurende het gehele Holoceen, zal minder variatie op lokaal niveau kunnen laten zien, dan een studie die onderzoekt hoe op één bepaald moment in de tijd de vegetatie in en rond een nederzetting eruit zag. In dit proefschrift richt ik me op het gedetailleerd reconstrueren van vegetatie op een regionaal, of zelfs lokaal niveau, specifiek in kustgebieden. Dit type gedetailleerde reconstructie is zowel relevant voor het helpen beantwoorden van specifieke archeologische vragen, als ook voor het verbeteren van de visualisatiemogelijkheden van historische landschappen en vegetatiemozaïeken aan zowel archeologen als geïnteresseerde leken. In de hoofdstukken 1 en 2, komt de theorie achter vegetatiereconstructie uitgebreid aan bod.

Twee gebieden die in ruimte en tijd behoorlijk uit elkaar liggen, worden gebruikt om voor de archeobotanie nieuwe analysetechnieken toe te passen. Het eerste gebied is een door een dik pakket klei afgedekt klein rivierensysteem in de huidige Flevopolder. Op smalle oevers in dit rivierensysteem bevonden zich tussen ongeveer 4300 en 4000 voor Christus nederzettingen van de Swifterbantcultuur. Een gedetailleerde reconstructie van de vegetatie van het Swifterbantgebied wordt gepresenteerd in hoofdstuk 3. Het tweede gebied is bekend als het Terpengebied van het kleigebied van Noord-Nederland. In dit onderzoek richt ik me op de periode tussen ongeveer 700 voor Christus en de aanleg van de eerste dijken. In hoofdstuk 5 wordt al het archeobotanisch onderzoek aan macroresten dat tot nu toe in het terpengebied is gedaan opnieuw geanalyseerd en geïnterpreteerd. Beide gebieden zijn klassieke onderzoeksgebieden van het Groninger Instituut voor Archeologie. Op botanisch vlak is in het bijzonder het werk van W. van Zeist van grote betekenis geweest. Hoewel deze studie een verregaande update is, blijft zijn werk van grote relevantie.

VEGETATIERECONSTRUCTIE | De uitdaging in vegetatiereconstructie, is om aan de hand van een lijst met plantenresten, te komen tot een beeld van hoe het landschap begroeid was. Een groot probleem daarbij is, dat de monsters die in de archeobotanie onderzocht worden meestal een mengsel zijn van planten die op hele andere plekken stonden. Hierbij is, zeker op het gedetailleerde niveau in dit proefschrift, dus niet alleen van belang welke soorten er aanwezig waren, maar vooral ook hoe die zich tot elkaar verhouden hebben. Het verschil tussen een lijst met planten en een beschrijving van hun ruimtelijke co-existentie, is vergelijkenderwijs te formuleren als het verschil tussen de begrippen flora en vegetatie.

Er zijn twee hoofdbenaderingen om soortenlijsten te vertalen naar vegetaties. De eerste benadering is om de planten te verdelen in zogenaamde *ecologische groepen*: de waterplanten bij de waterplanten en de graslandplanten bij de graslandplanten. Deze ecologische groepen kunnen uit bekende literatuur worden overgenomen, maar ze kunnen ook gevormd worden op basis van de individuele tolerantiewaarden van de soorten voor abi-

otische factoren als saliniteit of vochtgehalte. Bij deze indeling worden er dus kunstmatig groepen gemaakt. De soorten in zo'n groep komen in praktijk lang niet altijd ook daadwerkelijk samen voor. Bij ecologische groepen kunnen er soorten als waterplant zijn aangemerkt, die samen zelden of nooit optreden op dezelfde locatie, bijv. wegens verschillende affiniteit met waterkwaliteitsparameters. Een nadeel van het gebruiken van vast gedefinieerde ecologische groepen, is dat met name soorten met een wat bredere ecologie, te rigide, of soms zelfs onjuist, ingedeeld worden. Een goed voorbeeld is de grote brandnetel (*Urtica dioica*), die zowel in een braamstruweel als in een elzenbroekbos als aan de rand van een akker kan voorkomen, en daarnaast nog op vele andere plekken.

Een andere benadering is die van de plantensociologie, of vegetatiekunde. De vegetatiekunde maakt gebruik van vegetatieopnames in het veld om te onderzoeken welke planten onder bepaalde voorwaarden samen optreden. Een vaak samen voorkomende combinatie van soorten wordt een plantengemeenschap genoemd. Een belangrijk verschil met ecologische groepen is dus, dat alle planten die tot een bepaalde plantengemeenschap behoren, in het veld ook frequent samen waargenomen zijn.

Een belangrijk begrip in de archeobotanie, maar ook paleo-ecologie als geheel, is het zogenaamde actualiteitsprincipe. Dit principe gaat er van uit dat het heden als 'sleutel voor het verleden' gebruikt kan worden. Dit wil zeggen dat het valide is om hedendaagse waarneming aan organismen, in dit proefschrift vooral hogere planten, te gebruiken om het verleden te begrijpen en reconstrueren. Ik ga daarin in een aantal hoofdstukken van dit proefschrift vrij ver, en de discussie omtrent deze problematiek komt dan ook veelvuldig ter sprake (met name in de hoofdstukken 2, 3 en 6).

HET RIVIERENSYSTEEM VAN SWIFTERBANT | Een uitgebreide analyse van zowel oude als nieuwe botanische monsters uit het Swifterbantgebied wordt gepresenteerd in hoofdstuk 3. De vegetatie op de smalle oevers van Swifterbant bestond, met name langs de grotere rivierarmen, uit wilgenvloedbossen (*Salicion*) en pioniervegetatie uit de tandzaadklasse (*Bidentetea*). Op hogere smalle

oevers groeiden zachthoutooibossen, en in de kommen achter de smalle oevers groeide riet en kwamen elzenbroekbossen voor (*Alnetum*). Op de permanent droge en voedselarmere duinen stonden grote eiken. Dit zijn natuurlijke vegetatietypen, die alle herkend konden worden door de analyse van slechts drie monsters, afkomstig uit een vloedmerk op de oever van Swifterbant vindplaats S4. Uit een analyse van de monsters die genomen zijn in de nabijgelegen vindplaats Swifterbant S3, kwamen duidelijk de aan de tandzaadklasse verwante pioniergemeenschappen uit de akkeronkruidklasse (*Stellarietea*) en de klasse van nederzettingsvegetatie (*Artemisietea*) naar voren. Deze gegevens duiden erop dat de invloed van de mens op de vegetatie in het krekensysteem beperkt was, en niet ver voorbij de nederzetting zelf reikte.

Ook wijst deze analyse uit dat het landschap gedomineerd werd door vegetatietypen die kenmerkend zijn voor een landschap waarin periodiek overstroming plaats vindt, ook in de nederzettingen zelf. Hieruit kan geconcludeerd worden dat er hoogstwaarschijnlijk sprake was van seizoensbewoning. Wel biedt deze overstroming ook een hoge aanwas van mineralen. Dit biedt kansen voor akkerbouw. Akkerbouw in Swifterbant is lang onderwerp geweest van discussie, maar deze discussie is recentelijk beslecht doordat bij opgravingen onmiskenbare akkersporen zijn aangetroffen. Ook uit dit onderzoek komt naar voren dat akkerbouw ter plaatse uitgevoerd is. Zowel Emmertarwe (*Triticum turgidum* subsp. *dicoccon*) als naakte meerrijige gerst (*Hordeum vulgare* subsp. *vulgare*) zullen lokaal verbouwd zijn.

Door analyse van de vegetatie kon ook worden aangetoond dat vrijwel alle vegetatietypen die kenmerkend zijn voor klassieke laagveenvorming in het gebied konden worden aangetroffen. Hoewel dit ecologisch ook wel voor de hand ligt, is dit paleo-ecologisch een relevante observatie. In de paleo-ecologie, en meer in het bijzonder de palynologie, bestaat een sterke traditie in het benadrukken van de successie in vegetatie, maar minder in het benadrukken van zonering in de ruimte.

HET TERPENGEBIED | Het terpengebied is vanuit landschappelijk oogpunt voor veel mensen vrijwel synoniem met het kweldergebied. Hierbij wordt met name aan het zoutgehalte van dit land-

schapstype doorgaans veel aandacht geschonken, door middel van termen als 'zilte graslanden' en het frequent noemen van de heden ten dage vooral op de waddeneilanden voorkomende associatie van zilte rus (*Juncetum gerardii*).

Uit de in hoofdstuk 5 gepresenteerde analyse van meer dan 300 archeobotanische monsters van meer dan 40 vindplaatsen verspreid over het gehele terpengebied, komt met name naar voren dat de klassieke karakteriseringen een veel te uniform beeld suggereren, er moet veel meer variatie in de ruimte zijn geweest. Een ander belangrijke constatering is bovendien dat er aanzienlijke menselijke invloed op de vegetatie moet zijn geweest. Deze invloed is direct, in de vorm van begrazing, afplaggen en hooien, maar ook indirect door kunstmatige drainage (het graven van sloten) en het aanleggen van zomerdijken.

Dit betekent niet dat de analogie met het kweldergebied niet klopt. Een vergelijking met een recente typologie voor kweldervegetatie laat zien dat de typische kweldervegetatie een constante factor vormt in het landschap rond de terpen. Ook binnen de grenzen van de kwelder als analogie, bestaat er de mogelijkheid om een meer divers oud kwelderlandschap te reconstrueren, wanneer rekening wordt gehouden met het feit dat ook in de huidige kwelder intensievere en minder intensief gebruikte delen zijn. Wel zal het landschap in de directe omgeving van de terpen zelf in veel gevallen aanzienlijk meer door mensen beïnvloed zijn geweest dan veel van de huidige buitendijkse kwelderdelen. Grote delen van het landschap zullen langere tijd niet overstroomd zijn geraakt. In combinatie met vrij intensieve exploitatie leidde dit tot uitgestrekte brakke- tot zoete graslanden, en niet zozeer zilte graslanden.

Bomen waren in het gehele terpenlandschap, ook op de terpen zelf, nagenoeg afwezig. De enige uitzondering hierop vormt de vlier (*Sambucus nigra*). Deze was waarschijnlijk goeddeels gebonden aan beschutte delen op de terp, zoals de rand van drinkdobben. In deze dobben groeiden waterplanten die kenmerkend zijn voor zoet tot brak water. Dit type aquatische vegetatie kon zich niet ontwikkelen in de sloten in het open kwelderlandschap wegens het hogere zoutgehalte.

In alle door mij onderzochte terpen is tarwe aangetroffen (zie hoofdstuk 6), in de meeste gevallen Emmertarwe (*Triticum*

turgidum subsp. *dicoccon*) en in twee terpen, Firdgum en Ooster-
beintum, zelfs rogge, dat normaal als een typisch 'zandgraan'
wordt gezien. Dit past in een beeld van een terpenlandschap
met meer diversiteit, waarin het in veel gevallen wel degelijk
mogelijk was om ook deze gewassen ter plaatse te verbouwen.
Een goed overzicht van voedselplanten in het Nederlandse
terpengebied is een vooralsnog ontbrekende, maar belangrijke
volgende schakel in onze kennis van het terpengebied. De door
dit onderzoek beschikbaar gekomen data vormen daar een goed
startpunt voor.

Meer onderzoek is ook nodig naar de overgangszone tus-
sen de pleistocene zandgronden en de kweldergronden. Daarnaast
is het interessant om eens een intensieve studie te doen naar de
akkeronkruidvegetatie in het terpengebied. Bij cultivatie in een
kwelderlandschap moet een onkruidsamenstelling aanwezig zijn
geweest, die geen goed gelijkende plantengemeenschap kent in de
huidige vegetatie van Nederland.

TOEGEPASTE ANALYSETECHNIEKEN | Om tot een gedetailleerde re-
constructie van de vegetatie in de studiegebieden te komen, wor-
den een aantal verschillende methoden toegepast. In hoofdstuk
2 wordt een nieuwe methode gepresenteerd, PALAEOASSOCIA,
waarin aan de hand van ruim vijfhonderdduizend vegetatie-
opnamen die voor Nederland beschikbaar zijn, wordt berekend
wat de kans is dat in een archeobotanisch monster samen voor-
komende soorten ook samen in de vegetatie hebben kunnen co-
existeren. Een simpele introductie in de methode is opgenomen
in hoofdstuk 3. De methode is een variatie op het programma
ASSOCIA, een bestaande methode voor het identificeren van hui-
dige vegetatieopnames.

Van een archeobotanisch monster worden met behulp
van een associatiematrix overlappende soortengroepen gevormd,
waarbij dus de volledige ecologische amplitude van de verschillen-
de soorten in beeld komt. Ook algemenere soorten, die in klassie-
ke analyses beperkte indicatieve waarde hebben, spelen daardoor
een belangrijke rol in de vegetatiereconstructie. Voor de verschil-
lende groepen wordt bepaald met welke hedendaagse plantenge-
meenschappen deze de grootste overeenkomst vertonen.

De validiteit van het actualiteitsprincipe wordt bij vegetatiereconstructies met name betwist in sterk door mensen beïnvloede vegetatie. Daar archeologische opgravingen zich vrijwel uitsluitend richten op nederzettingen, zijn plantenresten uit deze typen vegetatie altijd sterk vertegenwoordigd in archeobotanische monsters. In Box 1 wordt duidelijk dat zowel een indeling in ecologische groepen, als een analyse door middel van PALAEOASSOCIA, problemen heeft met het herkennen van non-analoge akkervegetatie.

In het Swifterbantgebied, wordt de methode toegepast op vrijwel alle uit het gebied beschikbare monsters. De complexiteit van de methode en de omvang van de dataset maakt dit voor het terpengebied onmogelijk. Daarom is in hoofdstuk 5 een serie technieken toegepast voorafgaand aan de PALAEOASSOCIA-analyse, om tot een selectie van monsters te komen die tot een goed beeld van de gehele variatie in vegetatie leiden die vroeger in het gebied aanwezig moet zijn geweest. Met behulp van de Sørensen-index is bepaald welke monsters en vindplaatsen uit het terpengebied het meest afwijken van de anderen, en welke juist het meest 'gemiddeld' zijn. Ook is een index gevormd op basis van een zeer recente nieuwe typologie voor het waddengebied. Deze index berekent niet zozeer hoe zout, zoet of nat een monster is, maar meer in welke mate het overeenkomt met de huidige kweldervegetatie. In het Nederlands zou je het een kwelderindex kunnen noemen.

De diversiteit in het terpengebied is in beeld gebracht door middel van seriatie en principale componentenanalyse (PCA) of hoofdcomponentenanalyse. In hoofdstuk 6 wordt met een Mann-Whitneytoets een aanzet gedaan tot een volgende stap: het toetsen van de statistische significantie van in deze methoden geobserveerde patronen. Het toepassen van statistische toetsen op archeologische data wordt echter sterk bemoeilijkt doordat de dataset die bijeen is gebracht uit bestaande publicaties van veel oncontroleerbare factoren in de afzonderlijke onderzoeken afhankelijk is, waardoor het moeilijk te bepalen is wat je nu feitelijk toetst.

De toegepaste analysetechnieken vergroten de kennis over zowel het terpengebied als het Swifterbantgebied, maar belangrijker is de conclusie dat door het toepassen van nieuwe

analysemethoden op bestaande data nieuwe inzichten verkregen kunnen worden. Bij traditionele botanische categorieën ('proxies') als plantaardige macroresten, komt hier nog het voordeel bij dat er grote hoeveelheden data beschikbaar zijn.

BEMONSTERING EN VORMING VAN HET ARCHIEF | Een laatste hoofdonderwerp van deze dissertatie is de relatie tussen wat er in een monster wordt aangetroffen en wat de samenstelling van de vroegere vegetatie is geweest. Hierbij spelen een aantal belangrijke aspecten een rol.

Belangrijk is ten eerste om vast te stellen dat een nadeel van plantaardige diasporen is, dat ze een zeer zwakke kwantitatieve relatie hebben met de staande vegetatie. Deze zwakke relatie is niet voorbehouden aan archeobotanisch onderzoek. Grote verschillen in dispersie-eigenschappen als zaadproductie en zaadverspreiding leiden al in de actuele situatie tot een gecompliceerde verhouding tussen zaden in een zaadbank en staande vegetatie.

In archeologisch onderzoek wordt een deel van de vroegere soorten niet teruggevonden omdat de resten niet bewaard blijven of omdat ze niet op basis van de zaadmorfologie tot op soortniveau gedetermineerd kunnen worden. Daarnaast worden zelden tot nooit 'zaadbanken behorend tot uniforme begroeiingstypen' onderzocht. Meestal wordt gekozen voor archeologische 'contexten' die op het oog een sterk organische component hebben, zoals mestpakketten of slootvullingen.

De relatie tussen hooilanden en mest wordt onderzocht in hoofdstuk 4. Door middel van een experimentele studie kon worden aangetoond dat zaden uit mest gevormd uit hooi een goede kwalitatieve afspiegeling vormen van het grasland dat voor het betreffende hooi gemaaid is. Kwantitatieve conclusies kunnen beter getrokken worden aan de hand van de frequentie waarin een soort optreedt, dus door een aantal monsters uit mestafzettingen te nemen, dan door de getelde aantallen zaden.

In dynamische kustlandschappen zijn lange doorgaande sequenties van organisch materiaal, zoals die op de pleistocene gronden bekend zijn van pingoruïnes, afwezig. Voor een beeld van het landschap buiten de nederzettingen is het dan ook van

belang om te kijken naar andere manieren om iets over dat land-schap te weten te komen. Dit kan door in een nederzetting te zoeken naar monsters die resten van vegetatie van buiten de terp zelf kunnen bevatten. In het ideale geval bevat zo'n monster het signaal van slechts één vegetatietype, in welk geval we spreken van een schoon monster, of 'reine Probe'. Een klassiek voorbeeld is een concentratie van een voedselgewas, waarbij de wilde plan-ten mogelijk de vroegere akkerflora vertegenwoordigen (Box 1).

Een probleem van monsters uit de nederzetting, is dat met behulp van bijvoorbeeld ᴘᴀʟᴀᴇᴏᴀssᴏᴄɪᴀ (hoofdstuk 2) aan de hand van een aantal monsters wel te bepalen is wat de diver-siteit aan plantengemeenschappen in een gebied geweest moet zijn, maar dat niet voor alle delen van het landschap makkelijk bepaald kan worden welke van de geïdentificeerde vegetatie-typen daar voor kwam. In het Swifterbantgebied heb ik daarom enkele monsters van de top van het veen in de komgronden van het rivierensysteem genomen. Hoewel het ingewikkeld is om deze qua datering direct te linken aan de nederzettingen, geven ze wel een goed beeld van de potentiële diversiteit van deze land-schapsdelen.

In Box 2 pleit ik aan de hand van twee voorbeelden voor het vaker bemonsteren van sloten en kreken op grotere afstand van de nederzetting. Zeker in het terpengebied worden sloten dikwijls buiten de terpen zelf aangetroffen, vooral bij grootscha-lige infrastructurele grondwerkzaamheden.

ALGEHELE CONCLUSIE | Door het toepassen van nieuwe ana-lysetechnieken en het samenvoegen van grote hoeveelheden data is het mogelijk een veel genuanceerder en gedetailleerder beeld te krijgen van de vroegere vegetatiesamenstelling van een landschap. Dit beeld helpt bij het begrijpen van het handelen van de mens in het verleden, en met name in de diversiteit van het handelen van de mens in het verleden. Door de gradiën-ten in een landschap te koppelen aan gradiënten in vegetatie, ontstaat bovendien een reconstructie van het verleden die bij-draagt aan een beter begrip van hoe dat landschap er voor de mens in het verleden uit moet hebben gezien en deze dit heeft kunnen exploiteren.

Dankwoord

Hoewel je natuurlijk nooit te oud bent om te leren, beschouw ik dit op mijn 30e voltooide promotietraject toch een beetje als het einde van mijn opleiding. Ongetwijfeld zal ik nog wel weer eens ergens cursist in zijn, maar 'student', Deo volente, nooit meer. Deze pseudo-filosofische constatering dient als inleiding voor een dankwoord waarin ik de mensen die de afgelopen jaren van betekenis voor me zijn geweest probeer te noemen, zonder de pretentie te hebben dat ik niemand vergeet die hierin zeker een plaatsje had verdiend. Excuus aan diegenen die zich hieronder menen te mogen scharen.

Zonder mensen als juf Inge en meester Oosting van CBS de Wegwijzer in Zuidbroek, of mevrouw Van 't Wout en meneer Stevens van het Aletta Jacobs College in Hoogezand tekort te willen doen, begin ik gemakshalve na de middelbareschoolperiode. Dat begint niet met archeologie, laat staan archeobotanie, hoewel achteraf voor goedwillenden toch wel een patroon zichtbaar lijkt te worden. Omdat ik 'geen idee' had wat ik wou gaan studeren,

besloot ik dat ik beter eerst maar eens echt wat van de wereld kon gaan zien, wat neerkwam op een jaar werken in de twee kilometer verderop gelegen broodfabriek Veenhuis en Van der Molen te Sappemeer. Geef ons heden ons dagelijks brood in het kwadraat. Naast veel plezier met en waardering voor de mensen in die broodfabriek, leverde dit me ook de overtuiging op dat het misschien het overwegen waard was om dit niet de komende 45 jaar te doen.

Mijn moeder mag graag de anekdote opvoeren dat mijn uiteindelijke studiekeuze zich, na lang aandringen, openbaarde in de woorden: 'doe dan maar archeologie'. De rest is dus archeologie. Ik kwam in een uitermate vrolijke lichting terecht en heb enkele goede vrienden aan mijn studietijd overgehouden, met name Jasper Vosselman en Wouter Ytsma. Absolute hoogtepunten waren de mooie trips naar Halos met Reinder Reinders, de excursie Denemarken met Johan Nicolay en Bjørn Smit en, eveneens met Bjørn, de opgravingen bij Epse-Noord. Gedurende mijn bachelorfase was ik ondertussen gebiologeerd geraakt door de botanische kant van de archeologie: de archeobotanie.

In de zomer van 2006 werd bij opgravingen onder leiding van prof. Daan Raemaekers een zwartgrijze band drek aangetroffen, tegen de oever van een kleine rivierarm, waarop de vindplaats Swifterbant S4 lag (en deels nog ligt). Hoewel in de eerste velddocumentatie als 'aslaag' aangemerkt, werd al snel duidelijk dat het hier om een zogenaamde aanspoelselgordel of vloedmerk ging. Deze vondst kan met terugwerkende kracht als het startpunt van mijn promotietraject worden beschouwd. De gegevens van de botanische analyse die we uitvoerden op monsters uit dit spoor, werden door Niek Scheepens, destijds biologiestudent, gebruikt voor een vernieuwende vegetatiekundige analyse. Dit is uiteindelijk de basis geweest voor hoofdstuk 2 van dit proefschrift.

Na mijn afstuderen ging ik na een korte periode bij Archeopro aan het werk bij het inmiddels niet meer bestaande ARC. Ik kreeg daar alle ruimte en vertrouwen van Cuno Koopstra om mij verder te ontwikkelen als archeoloog én botanisch specialist. Cuno en ik hebben ook na mijn periode bij ARC veel contact gehouden, en zijn tegendraadse kijk op vorm en inhoud zijn een blijvende stimulans om goed en kritisch over dingen na te blijven denken.

Tijdens mijn promotieonderzoek heb ik veel gehad aan mijn collega's aan de Broerstraat, en niet alleen 'de botanici'. De levendige koffiecolleges van Gert over wat nu wel en niet kunst is, waarbij ik mezelf de vrijheid permitteer her en der wat wars te denken, had ik voor geen goud willen missen. Daarnaast was Gert meer dan bereid om mee te denken met mijn onderzoek, en waar nodig de endocarp van een meidoorn te halveren. Tijdens mijn promotieonderzoek liep er ook een enthousiaste schare studenten rond, waarvan een groot aantal aan mijn project gerelateerde onderzoeken heeft uitgevoerd. Met name wil ik daarbij Yasmijn, Jelte, Merit en Simone noemen. Federica had niets met mijn onderzoek te maken, maar alles met botanie. Federica, succes met het afronden van jouw verhaal! Rita's steun en oprechte interesse in mijn familie en onderzoek zijn absoluut onmisbaar geweest en ik heb veel met haar gelachen. Rita, laat je niet gek maken, je wordt gewaardeerd! De aanwezigheid van eminences grises Nicolien en Henk op de achtergrond is vooral voor mijn veldkennis van ongekend belang geweest. Sylvia: bedankt voor de dropjes!

Ik kwam ook wel eens aan 'de overkant'. Ik heb daar kennis gemaakt met Stijn. Zijn literatuurkennis, scherpzinnigheid en schier oneindige softwarevaardigheid, rechtvaardigen de stelling dat dit proefschrift er zonder hem beslist niet gekomen was. Veldwerk rond al dan niet bestaande grafheuvels en zeker bestaande celtic fields leidden ook tot mooie discussies in het veld, zoals het hoort: lekker vol erin. Bij dat veldwerk, en ook bij eerder veldwerk, was Inger er eigenlijk ook altijd. Inger, we hebben superveel lol gehad, en vond het erg gezellig dat je een paar maandjes bij me kwam wonen!

De komst van Gilles als hoogleraar terpenarcheologie luidde ook het begin van het Terpencentrum in. Ik heb dat als een bijzonder welkom initiatief beschouwd en hoop dat ik er nog lang bij betrokken mag blijven. De ruimte die Johan me bood bij botanisch onderzoek aan terpen is fantastisch geweest en de resultaten zijn volgens mij ook uitermate boeiend. En meer komt...

Een onmisbaar onderdeel van het promotietraject is natuurlijk schrijven. Ik heb nooit last gehad van een writer's block, maar heb nog wel eens de neiging wat rommelig te zijn of gedach-

ten wat te snel uit te schrijven. Een aantal mensen hebben de moeite genomen eens kritisch naar dingen te kijken, onder wie Annet, Theo en Otto. De start van een 'schrijfclubje', de zogenaamde 'GIA Paper Writing Support Squad' heb ik ook als bijzonder nuttig en gezellig ervaren. Corien, Eleni, Francesca, Frigga, Gary, Kayt, Olivia, Sandra, Sarah, Tamara, Tanja, Wieke: ik hoop af en toe te blijven komen disucssiëren. Niet in de laatste plaats bedank ik natuurlijk de co-auteurs van mijn artikelen. De niet-GIA-mensen daaronder, Henk, Niek en Onno, verdienen met name mijn dank voor het veelvuldig heen en weer mailen. Enige extra dank aan Onno is hier op zijn plaats. Ik heb veel van je geleerd in korte tijd en ben trots dat je in mijn proefschrift staat.

Natuurlijk ben ik mijn promotoren voor raad en discussie veel dank verschuldigd. Renée: ik ben blij dat je naast co-auteur ook co-promotor geworden bent. Je nimmer aflatende positivisme in combinatie met een soepel snorrend brein had ik niet kunnen missen. Ik heb je bijdrage als een groot geluk ervaren. Daan en René: mijn dank aan jullie begint eigenlijk al ver voor mijn promotie. Colleges en veldwerk met jullie heb ik als inspirerend ervaren en ik ben dan ook blij dat jullie er heil in zagen mij voor dit avontuur aan te stellen. Volgens mij hebben we er met zijn allen een mooi project van gemaakt. De veldexcursies die René geïntroduceerd heeft, waarbij het kennen van de flora en het begrijpen van het archeobotanisch archief centraal stonden, hebben mijn onderzoek een eigen karakter gegeven, en René's invloed is in mijn proefschrift dan ook duidelijk zichtbaar.

Arnoud, jij zou zowel als studievriend, als student, als collega en inmiddels ook als co-auteur in dit dankwoord kunnen staan. Dat is uitermate onoverzichtelijk gedrag van je. In ieder geval is je ruggenspraak op menselijk en inhoudelijk vlak al jaren erg waardevol en ik hoop dat dat zo blijft, in welke vorm dan ook.

Ik wil hier ook mijn beide paranimfen nog speciaal bedanken. Welmoed: als goede vriendin én collega in de archeobotanie ben je de afgelopen jaren op velerlei wijze van grote invloed geweest. Via een Groningse afscheidsborrel rijkt deze invloed tot aan mijn gezinssamenstelling. Ik hoop op veel vriendschap en samenwerking in de toekomst. Onze deur staat altijd voor jullie open. Miranda: je verstandige kijk op van alles in mijn leven,

niet in het minst ook mijn geknutsel buiten de directe archeologiesores, leiden tot relativering en vrolijkheid. Laten we onze afspraakjes er lekker in houden!

Ik ken natuurlijk niet alleen maar archeologen. Goede vrienden als Annelies, Berend en Leonie zorgden bij kroeg, kamp en concert voor welkome afleiding. Sjoerd, jij bent niet iemand die er vreselijk op zit te wachten om in zo'n dankwoord te staan. En dan toch. Ik ben blij dat ik je als vriend heb en hoop dat je olie vindt.

Mijn ouders zijn natuurlijk de basis van alles. De laatste jaren hebben ze zelf, en dan met name mijn moeder, ook wel wat hordes te nemen gekregen. Dat ze ondanks dat iedere maandag hun kleindochter opvangen, auto's voor ons regelen, tripjes naar Duitsland ondernemen én interesse in mijn proefschrift hebben getoond is ongelofelijk. Pap en mam bedankt. Jullie steun was en is onmisbaar.

Ergens halverwege mijn proefschrift gebeurde er iets wonderlijks. Mijn lieve vriendin Kirsten kwam in mijn leven, en hoe... Met haar kwam, pakweg 10 maanden later, Nena. Ik had graag gezien dat mijn proefschrift enkele maanden eerder klaar was. Dat dat niet is gebeurd, heeft als feestelijk bijeffect dat ik hier nu ook Jonne kan noemen. Het krijgen van kinderen tijdens je promotie, daar is vast van alles over te zeggen. Ik kan alleen maar zeggen dat Nena en Jonne, me iedere dag veel meer energie geven dan dat ze me kosten. Dat laat onverlet dat Kirsten natuurlijk de drijvende kracht in het geheel is. Kirsten, dankjewel. Dit varkentje is gewassen.

List of publications

Raemaekers DCM, Geuverink J, Schepers M, Tuin BP, Van der Lagemaat E, Van der Wal M (2010) A biography in stone. Typology, age, function and meaning of Early Neolithic perforated wedges in the Netherlands (=Groningen Archaeological Studies 14). Barkhuis, Eelde

Schepers M (2008) Een archeologische inventarisatie van de staat van veenterpen in de polders Matsloot-Roderwolde en Peizer- & Eeldermaden, gemeente Noordenveld (Dr.)(=ARC-Publicaties 196). ARC, Groningen

Schepers M (2014) Wet, wealthy worlds: the environment of the Swifterbant river system during the Neolithic occupation (4300–4000 cal BC). J Archaeol Low Ctries 5:79-105

Schepers M, Cappers RTJ, Bekker RM (2013) A review of prehistoric and early historic mainland salt marsh vegetation in the northern-Netherlands based on the analysis of plant macrofossils. J Coast Conserv 17:755-773

Schepers M, Cappers R, Heijen I (2006) Neolithische graanopslag in de Fayum. Paleo-aktueel 17:55-62

Schepers M, Scheepens JF, Cappers RTJ, Van Tongeren OFR, Raemaekers DCM, Bekker RM (2013) An objective method based on assemblages of subfossil plant macro-remains to reconstruct past natural vegetation: a case study at Swifterbant, the Netherlands. Veg Hist Archaeobot 22:243-255

Thasing S, Van Klink R, Schepers M, Cappers RTJ, Brüning EBE (2012) Kevers en hun potentie voor onderzoek in het terpengebied. Paleo-aktueel 23:111-118

Woldring H, Schepers M, Mendelts J, Fens R (2012) Camping and foraging in Boreal hazel woodland – The environmental impact of Mesolithic hunter-gatherers near Groningen, the Netherlands. In: Niekus MJLTh, Barton RNE, Street M, Terberger Th (eds) A mind set on flint. Studies in honour of Dick Stapert (=Groningen Archaeological Studies 16). Barkhuis, Eelde, pp 381-392

Van den Bos V, Brinkkemper O, Bull ID, Engels S, Hakbijl T, Schepers M, Van Dinter M, Van Reenen G, Van Geel B (2014) Roman impact on the landscape near castellum Fectio, the Netherlands. Veg Hist Archaeobot 23:277-298

Van Rooij J, Cappers R, Schepers M (2007) De botanische samenstelling van mestkoeken en ashopen in relatie tot de reconstructie van akkervegetaties. Paleo-aktueel 18:80-85

Affiliation of co-authors

Renée M. Bekker. Groningen Institute of Archaeology, University of Groningen, Poststraat 6, 9712 ER Groningen, the Netherlands

René T.J. Cappers. Groningen Institute of Archaeology, University of Groningen, Poststraat 6, 9712 ER Groningen, the Netherlands

Daan C.M. Raemaekers. Groningen Institute of Archaeology, University of Groningen, Poststraat 6, 9712 ER Groningen, the Netherlands

Niek (J.F.) Scheepens. Plant Evolutionary Ecology, Institute of Evolution and Ecology, University of Tübingen, Auf der Morgenstelle 1, D-72076 Tübingen, Germany.

Onno F.R. van Tongeren. Data-Analyse Ecologie, Vrij Nederlandstraat 57, 6826 AW Arnhem, the Netherlands.

Henk van Haaster. BIAX Consult, Hogendijk 134, 1606 AL Zaandam, the Netherlands

Cow 1-3, Wageningen University, the Netherlands

Sheep 1-3, Wageningen University, the Netherlands

This dissertation delves into the reconstruction of past vegetation at the most detailed level. It is not the objective to focus solely on the developments in vegetation over time, but to create an image of the landscape that must have been visible to prehistoric people. Landscape and vegetation form a major starting point for the opportunities available in a certain area for a broad scale of human activities including grazing of livestock, cultivating crops and collecting wild plants. The majority of the analyses are based on seeds and fruits (botanical macro-remains) from two Dutch prehistoric regions. These are the small river system in the present Flevopolder, home to settlements of the so-called Swifterbant Culture in the Neolithic period (4300–4000 BC), and the Frisian-Groningen terp region in the period prior to the endikements (700 BC – ca. 1200 AD).