V. Pollen morphology and representation in surface samples of *Rumex acetosa* and *Rumex acetosella*

V.1 Introduction

A pollen type which often increases at the beginning of the Neolithic as represented in pollen diagrams and for that reason is considered a useful indicator of human activity, is *Rumex*-type (BEHRE 1981; see I.4.2). *Rumex acetosa* and *Rumex acetosella* are nowadays by far the most common and widespread species falling within this type. These two species are wind pollinators and produce very large amounts of pollen: for example, one inflorescence of *Rumex acetosa* produces ca. 393,000,000 pollen grains (POHL 1937). The two *Rumex* species are always well represented in surface pollen samples (see for example BRADSHAW 1981, table 4).
Some authors have regarded *Rumex*-type as indicative of pasture (TURNER 1964; DONALDSON & TURNER 1977), while other authors have selected it as indicative of arable land (RIEZEBOS & SLOTBOOM 1978). A first step leading towards the solution of this disagreement is the separation of the pollen of *Rumex acetosa* and *Rumex acetosella*. A second step comprises a study of the ecology of these two species. These steps are worked out in the next two sections: in V.2, the pollen morphology of these two species is studied; V.3 deals with the representation of the two species in surface pollen samples and in vegetation plots from vegetation types in which they play an important role. Section V.4 discusses how the results of this study can be used for the interpretation of the subfossil pollen diagrams.

V.2 Pollen morphology

Rumex species produce 3-zono- or (4-9) pantocolporate pollen grains. The ectocolpi are narrow and slit-like, long to very long. The endopori are circular, slightly lalongate (elongated in equatorial direction) or more or less lolongate (elongated in polar direction) in outline, with narrow but distinct costae, which are sometimes interrupted at the equator. The ornamentation is microreticulate (VAN LEEUWEN et al. 1988). Although the pollen of *Rumex* species are very similar, it is possible to recognize distinct pollen groups and sometimes even species (VAN LEEUWEN et al. 1988). In table 2, a small identification key is shown, used in this study for the subdivision of *Rumex*-type. All *Rumex* grains larger than 22 µm belong to *Rumex hydrolapathum*-type. In the subfossil pollen diagrams of the Gietsenveentje, only a few grains of this type were observed. All *Rumex* grains smaller than 22 µm belong to *Rumex acetosa/acetosella*. According to Van Leeuwen et al. (1988), not only *Rumex acetosa* and *Rumex acetosella* belong to this group, but also four other species. In table 4, some characteristics of these four species are summarized. *Rumex thyrsiflorus* and *Rumex triangulivalvis* are no native species of northwestern Europe, but are imported from central/eastern Europe and North America, respectively. *Rumex alpestris* and *Oxyria digyna* only occur in mountainous areas of Europe and arctic regions. The likelihood that any of these four species ever grew near the

Rumex-type	< 22 µm:	*Rumex acetosa/acetosella* Species: *R. acetosa*, *R. acetosella*, *R. alpestris*, *R. thyrsiflorus*, *R. triangulivalvis*, *Oxyria digyna* (see table 3 and 4)
	> 22 µm:	*Rumex hydrolapathum*-type Species: *R. aquaticus*, *R. bucephalophorus*, *R. conglomeratus*, *R. crispus*, *R. hydrolapathum*, *R. longifolius*, *R. maritimus*, *R. obtusifolius*, *R. palustris*, *R. patientia*, *R. pulcher*, *R. rupestris*, *R. sanguineus*, *R. scutatus*

Table 2. Subdivision of pollen of *Rumex*-type in this study. All measurements are in silicone oil.

Rumex acetosa L.	*Rumex acetosella* L.	Reference
relatively short colpi	long colpi	VAN LEEUWEN et al. 1988
non-intruding colpi	intruding colpi	VAN LEEUWEN et al. 1988
endoporus interrupted, circular or slightly lalongate	endoporus usually distinctly interrupted, often lalongate	VAN LEEUWEN et al. 1988
microreticulate	reticulate	MOORE et al. 1991
not dupli- or pluricolumellate; no slightly winding muri	dupli- or pluricolumellate with slightly winding muri	MOORE et al. 1991

Table 3. Characteristics of pollen of *Rumex acetosa* and *Rumex acetosella.*

Species	Biotope	Present distribution	Origin	Pollen resembles:	Differences in pollen
Rumex alpestris Jacq. (= *R. arifolius* All.)	meadows, mainly in the mountains	mountains of Europe	mountains of Europe	*Rumex acetosa*	lolongate endoporus
Rumex thyrsiflorus Fingerh.	moderately dry grassland, esp. along rivers	recently spreading as an alien into W. Europe	C. and E. Europe, Siberia	*Rumex acetosa*	none
Rumex triangulivalvis (Danser) Reichb. f.	brooksides	naturalized in N., W. and C. Europe	N. America	*Rumex acetosella*	lolongate endoporus
Oxyria digyna (L.) Hill	stony pastures, near melting snow	mountains of Europe, arctic regions	mountains of Europe, arctic regions	*Rumex acetosella*	distinct, circular endoporus; never 4-colporate

Table 4. Characteristics of *Rumex* and *Oxyria* species producing pollen which resembles pollen of *Rumex acetosa* or *Rumex acetosella* (TUTIN et al. 1964; VAN LEEUWEN et al. 1988).

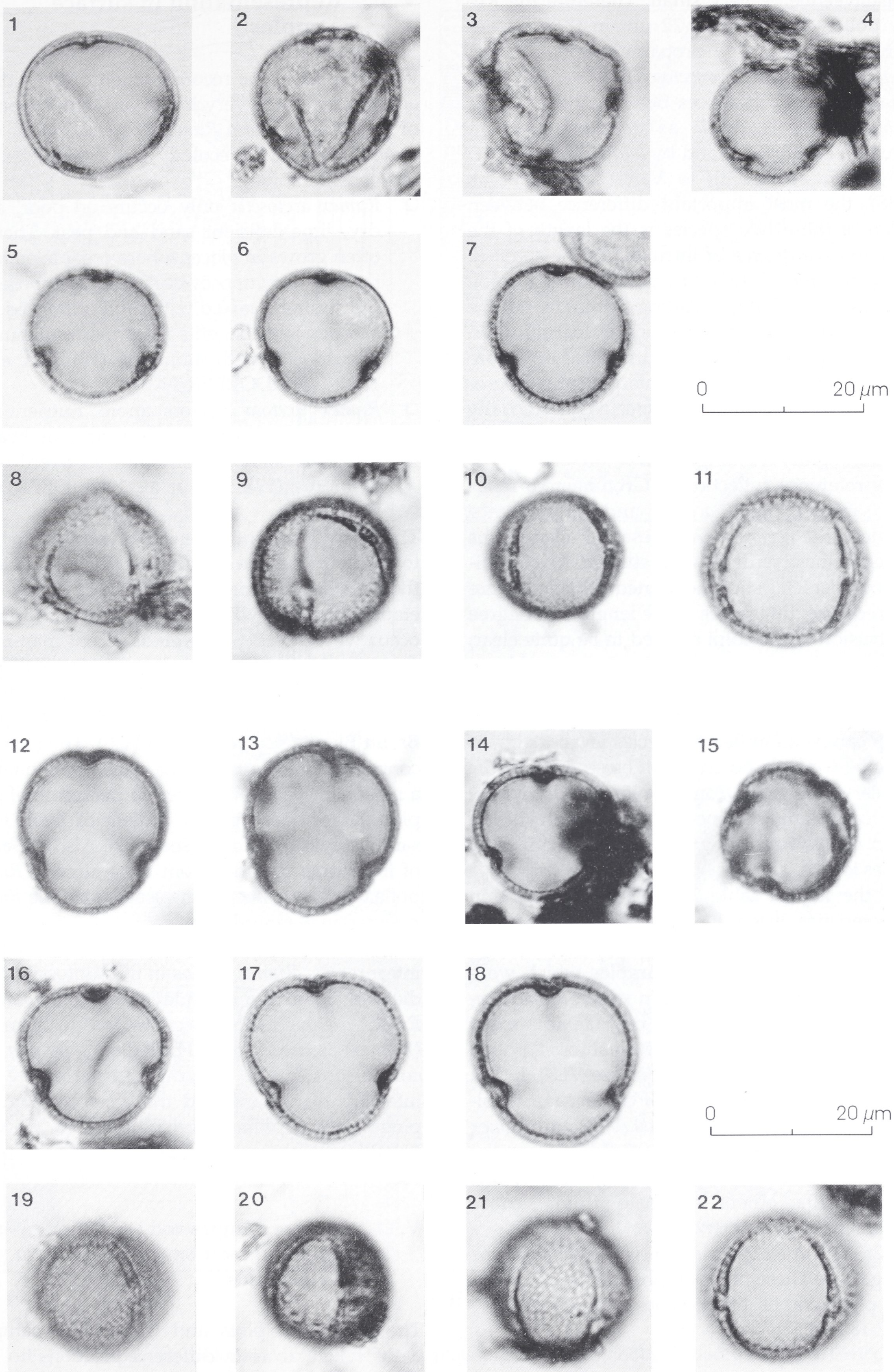
Fig. 31 (right). Pollen grains of *Rumex acetosa* and *Rumex acetosella*. Magnification 1250 x.

1-11 *Rumex acetosa*:

1. Gieten V-A 377-378 cm; 2. Gieten IV-P 335-336 cm; 3. Gieten V-B 215-216 cm; 4. Gieten V-A 366-367 cm; 5. surface sample N5; 6. surface sample N5; 7. reference sample BAI 4989; 8. Gieten V-B 215-216 cm; 9. Gieten V-A 366-367 cm; 10. surface sample N5; 11. reference sample BAI 4989.

12-22 *Rumex acetosella*:

12. Gieten V-A 59-60 cm; 13. Gieten V-A 59-60 cm; 14. Gieten V-A 366-367 cm; 15. Gieten IV-HR 355-356 cm; 16. surface sample H3; 17. reference sample BAI 4991; 18. reference sample BAI 4991; 19. Gieten V-A 59-60 cm; 20. Gieten IV-HR 355-356 cm; 21. surface sample H3; 22. reference sample BAI 4991.


1
2
3
4
5
6
7
0
20 μm
8
9
10
11
12
13
14
15
16
17
18
0
20 μm
19
20
21
22

Gietsenveentje, is very small. Therefore the *Rumex* pollen smaller than 22 µm in the Gietsenveentje diagrams very probably originates from *Rumex acetosa* or *Rumex acetosella*.
In table 3, the differences between pollen of *R. acetosa* and *R. acetosella* as described by Van Leeuwen et al. (1988) and by Moore et al. (1991) are shown. According to Van Leeuwen et al. (1988), the most important difference between pollen of these two species is the length of the colpi and the degree of intrusion of the colpi: *R. acetosa* has relatively short, non-intruding colpi; *R. acetosella* has long, intruding colpi. The outline of the endoporus is a less clear identification characteristic. The differences indicated by Moore et al. (1991) concern ornamentation type (microreticulate and reticulate, respectively) and the presence in *R. acetosella* of dupli- or pluricolumellate, slightly winding muri.
In the reference collection at Groningen, 6 reference samples of *R. acetosa* and 10 reference samples of *R. acetosella* are present. Pollen grains in each of these samples were studied. The identification characteristics mentioned in table 3 were checked. The differences in the length and degree of intrusion of the colpi seemed to be quite clear; the other identification characteristics could not be confirmed. It has to be emphasized that not each pollen grain of the *Rumex acetosa/acetosella* group can be identified to species level: the grain has to be well-preserved and it has to be possible to observe the grain from a polar perspective. In some cases, only a minority of the grains of the *Rumex acetosa/acetosella* group can be identified to species level.
With the key of table 2 and the identification characteristics listed in table 3, attempts have been made to separate pollen of *Rumex acetosa* and *R. acetosella* in surface samples which were collected in vegetation types in which *Rumex acetosa* and/or *Rumex acetosella* play an important role (see V.3), and also in the subfossil pollen diagrams of the Gietsenveentje (see VI.3). In fig. 31, photographs are shown of characteristic pollen grains of *Rumex acetosa* (nos. 1-11) and *Rumex acetosella* (nos. 12-22). Some originate from the subfossil Gietsenveentje samples (nos. 1-4, 8-9, 12-15, 19-20); others originate from surface samples from Nietap (nos. 5-6, 10; locations see fig. 32d) and the Hijkerveld (nos. 16, 21; locations see fig. 32b). These photographs can be compared with photographs of reference samples (nos. 7, 11, 17-18 and 22).

V.3 Representation in surface samples

With respect to the reconstruction of the palaeoenvironment, it is very important that the pollen of *Rumex acetosa* and *Rumex acetosella* can be separated, because the ecology of these species differs considerably:

- *Rumex acetosella* only occurs on poor, acid, dry, lime-deficient sand and peat. There it often grows in places where organic material rapidly decomposes because it is exposed to full sunlight, mixed with sand or burned. *Rumex acetosella* benefits from the "enrichment" of acid soil with ammonia (WEEDA et al. 1985; OBERDORFER 1990);
- *Rumex acetosa* prefers more nutrient-rich, slightly acid soils. On very acid or heavily fertilized soils, it easily gets an overdose of ammonia (WEEDA et al. 1985; OBERDORFER 1990).

The study of recent vegetation types can help us to elucidate the role of these two *Rumex* species in the vegetation during the Neolithic. Recent vegetation types in which *Rumex* species naturally occur were studied, as well as recent man-made vegetation types in which *Rumex* species play an important role. Vegetation plots were recorded in different vegetation types with *Rumex*, using the Braun-Blanquet method (see IV.9). To study the contribution of *Rumex* to the pollen precipitation, a moss sample was collected in the centre of each plot. The modern pollen content of these moss samples was examined (see IV.9). Also the effect of increasing distance from the source of *Rumex* pollen and the effect of the seasons on the *Rumex* pollen rain was studied.
The results of the ecological study will be used to interpret the *Rumex* values in the subfossil pollen diagrams. Because nowadays *Rumex acetosa* and *Rumex acetosella* often occur in pastures and in (former) arable land (BEHRE 1981), possibly also conclusions can be drawn about the nature and intensity of farming and the distance from the pingo scar at which agriculture took place in Neolithic times.

V.3.1 Surface samples and vegetation plots from four locations in the northern Netherlands

The vegetation plots and the surface samples were taken at four different locations in the northern part of the Netherlands: Nietap (near

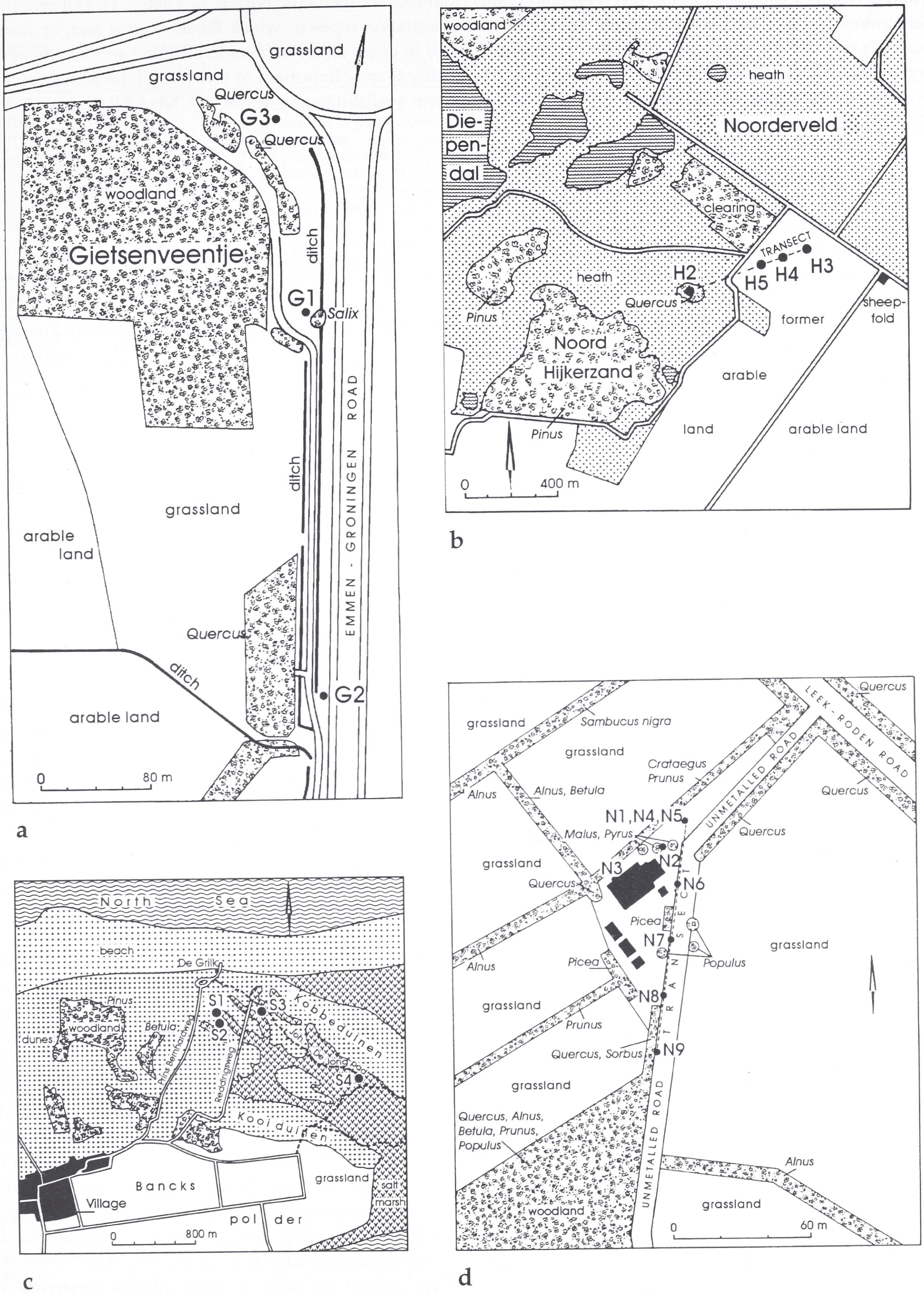


Fig. 32. Maps with the locations of the vegetation plots and the corresponding surface samples: a. Gieten; b. Hijkerveld; c. Schiermonnikoog; d. Nietap.

Table 5 (right). Plant species in twelve vegetation plots from four locations (N: Nietap, G: Gieten, H: Hijkerveld, S: Schiermonnikoog). The vegetation plots are recorded in vegetation types in which *Rumex acetosa* and/or *Rumex acetosella* play an important role. The plant species are placed in order of the nutrient availability and acidity of the soil at which their growing conditions are optimal (the acidity is only important at low nutrient availability). The numbers in the second column represent the following nutrient availability and acidity (RUNHAAR et al. 1987, 301; CAPPERS 1994):

1	low nutrient availability, acid
2	low nutrient availability, moderately acid to neutral
3	low nutrient availability, basic
4	low nutrient availability
7	moderate nutrient availability
9	moderate to high nutrient availability
8	high nutrient availability

The vegetation plots have been recorded according to the (extended) Braun-Blanquet method (see IV.9). The signs represent the cover of the different species within the plots:

r	one or a few individuals
+	< 25 individuals
1	< 100 individuals
2m	> 100 individuals
2a	5 ≤ cover < 12.5%
2b	12.5 ≤ cover < 25%
3	25 ≤ cover < 50%
4	50 ≤ cover < 75%

In plot H2, the Braun-Blanquet method has not been used; only two categories have been recognized:

M	present with many individuals
P	present

Roden, northwestern part of the province of Drenthe), Gietsenveentje, Hijkerveld (near Beilen, central part of Drenthe) and Schiermonnikoog (an island in the Wadden Sea, province of Friesland). At the first three locations, the vegetation is strongly influenced by man; however, the dune and salt-marsh vegetation of the island of Schiermonnikoog is hardly exposed to human influence.
In total, 12 vegetation plots were recorded. Table 5 lists all plant species observed in the plots. On the basis of the observed plant species, the plots are classified from nutrient-rich, which means a high nutrient availability in the soil (left) to nutrient-poor, which means a low nutrient availability in the soil (right). The pollen values from the corresponding pollen samples are shown in fig. 33. The order of the samples is the same as in table 5, ranging from nutrient-rich (above) to nutrient-poor (below). In principle, the diagram is constructed the same way as the subfossil pollen diagrams (see VI.3.1). Because the samples are not related chronologically, the pollen values of the samples are reproduced in bars.

Nietap
At Nietap, one vegetation plot was recorded on June 9th, 1994 near the home of H. Woldring, J.P. Santeeweg 117, in a nutrient-rich meadow, which was manured each year until nine years ago. The location of this plot is indicated in fig. 32d.
Vegetation plot N1. *Rumex acetosa* is dominant (25-50% cover), together with *Ranunculus acris/repens*. The most common grass is *Anthoxanthum odoratum*.
Pollen sample N1. The pollen picture correlates with the vegetation plot data: *Rumex acetosa* and *Rumex acetosa/acetosella* are dominant, Gramineae and *Ranunculus acris* group are quite common. It is notable that about 70% of the *Rumex* pollen could not be identified beyond *Rumex acetosa/acetosella*. Although *Taraxacum officinale* occurs quite frequently in the vegetation plot, pollen of Compositae Liguliflorae, the type to which pollen of *Taraxacum officinale* belongs, is scarcely observed in the pollen sample. Pollen of Compositae Liguliflorae is nearly always poorly represented in surface samples (BOTTEMA 1975, 21).
According to table 5, most plants occurring in this plot, including *Rumex acetosa*, prefer a moderate to high or moderate nutrient availability.

GROUP	Nutr. Avail. & acidity	Species	N1	G1	G3	G2	H3	H4	H5	H2	S4	S3	S2	S1
			Vegetation plot											
HIGH NUTRIENT AVAILABILITY	- - - - - - 8	Cirsium arvense					1		3		1			
	- - - - - - 8	Alopecurus geniculatus					r							
	- - - - - - 8	Poa annua					r	r	1	P				
	- - - - - - 8	Rorippa palustris						r	r					
	- - - - - - 8	Dactylis glomerata	+											
MODERATE TO HIGH NUTRIENT AVAILABILITY	- - - - 7 - 8	Holcus lanatus		2b	2a	2b	2b	r	+		+	3	r	2a
	- - - - 7 - 8	Poa trivialis	1											
	- - - - 7 - 8	Sagina procumbens									2m	r		r
	- - - - 7 - 8	Lythrum salicaria												+
	- - - - 7 - 8	Ranunculus acris/repens	4	2a										
	- - - - 7 - 8	Trifolium repens	r					r			1			
	- - - - 7 - 8	Bellis perennis	r											
	- - - - 7 - 8	Potentilla reptans												r
	- - - - 7 - 8	Cerastium fontanum	1						+		1	+	r	+
	- - 3 - 7 - 8	Bromus hordeaceus									2a			
	- 2 3 - 7 - 8	Taraxacum officinale s.l.	2a		r		2a	+	r					
	- 2 3 - 7 - 8	Poa pratensis	+								1	1	+	1
	1 2 3 - 7 9 8	Quercus robur								M				
	- - - - 7 9 -	Galeopsis tetrahit								P				
	- - 3 - - 9 -	Asparagus officinalis										r		
MODERATE NUTRIENT AVAILABILITY	- - - - 7 - -	Achillea millefolium		r		r								
	- - - - 7 - -	Plantago lanceolata		r	1									
	- - - - 7 - -	Rumex acetosa	3	2b	2a	+								
	- - - - 7 - -	Linaria vulgaris			1									
	- - - - 7 - -	Hypericum perforatum			r									
	- - - - 7 - -	Stellaria graminea		r	2a									r
	- - - - 7 - -	Veronica chamaedrys			1									
LOW TO MODERATE NUTRIENT AVAILABILITY	- - 3 - 7 - -	Erodium cicutarium											r	
	- - 3 - 7 - -	Myosotis ramosissima										+		r
	- - 3 - 7 - -	Veronica arvensis					r	r				r		r
	- - 3 - 7 - -	Senecio jacobea									r			r
	- 2 3 - 7 - -	Hypochaeris radicata			r	r								
	- 2 3 - 7 - -	Luzula campestris										2a	2b	2a
	- 2 3 - 7 - -	Festuca rubra		+	+	2b					2b			
	- 2 3 - 7 - -	Lotus corniculatus												+
	- 2 3 - 7 - -	Cerastium semidecandrum					1	2a	2a					
	- 2 - - 7 - -	Anthoxanthum odoratum	2a	1	1	2a								
	- 2 - - 7 - -	Campanula rotundifolia			2a									
	- 2 - - 7 - -	Rhinanthus angustifolius		r		r								
	- 2 - - 7 - -	Cirsium palustre										+		r
	- 2 - - 7 - -	Agrostis capillaris						r	2b					
	- 2 - - 7 - -	Chamerion angustifolium					r	r	1					
	1 2 - - 7 - -	Festuca ovina		+	3	3	2b	r		M			2a	2b
	1 2 - - 7 - -	Betula pubescens							r					
	1 2 - - 7 - -	Holcus mollis		3	1									
	1 2 - - 7 - -	Rumex acetosella			2a	+	2b	4	1	P	2b	2b	2a	2m
LOW NUTRIENT AVAILABILITY: MODERATELY ACID TO BASIC	- - - 4 - - -	Ammophila arenaria											+	1
	- - 3 - - - -	Cochlearia danica									+			
	- 2 3 - - - -	Aira praecox					3	2b	2b			1		
	- 2 3 - - - -	Polygala vulgaris												1
	- 2 3 - - - -	Carex arenaria									+	3	3	2a
	- 2 3 - - - -	Leontodon saxatilis											r	r
	- 2 3 - - - -	Galium verum											1	
	- 2 3 - - - -	Viola curtisii												+
	- 2 3 - - - -	Veronica officinalis			r							+		+
	- 2 3 - - - -	Stellaria holostea									1			
LOW NUTRIENT AVAILABILITY: ACID TO MODERATELY ACID	- 2 - - - - -	Teesdalia nudicaulis						r						
	- 2 - - - - -	Filago minima												r
	- 2 - - - - -	Viola canina										+	+	r
	- 2 - - - - -	Ophioglossum vulgatum												1
	- 2 - - - - -	Luzula multiflora		r										
	1 2 - - - - -	Galium saxatile								P				
	1 - - - - - -	Ceratocapnos claviculata								P				

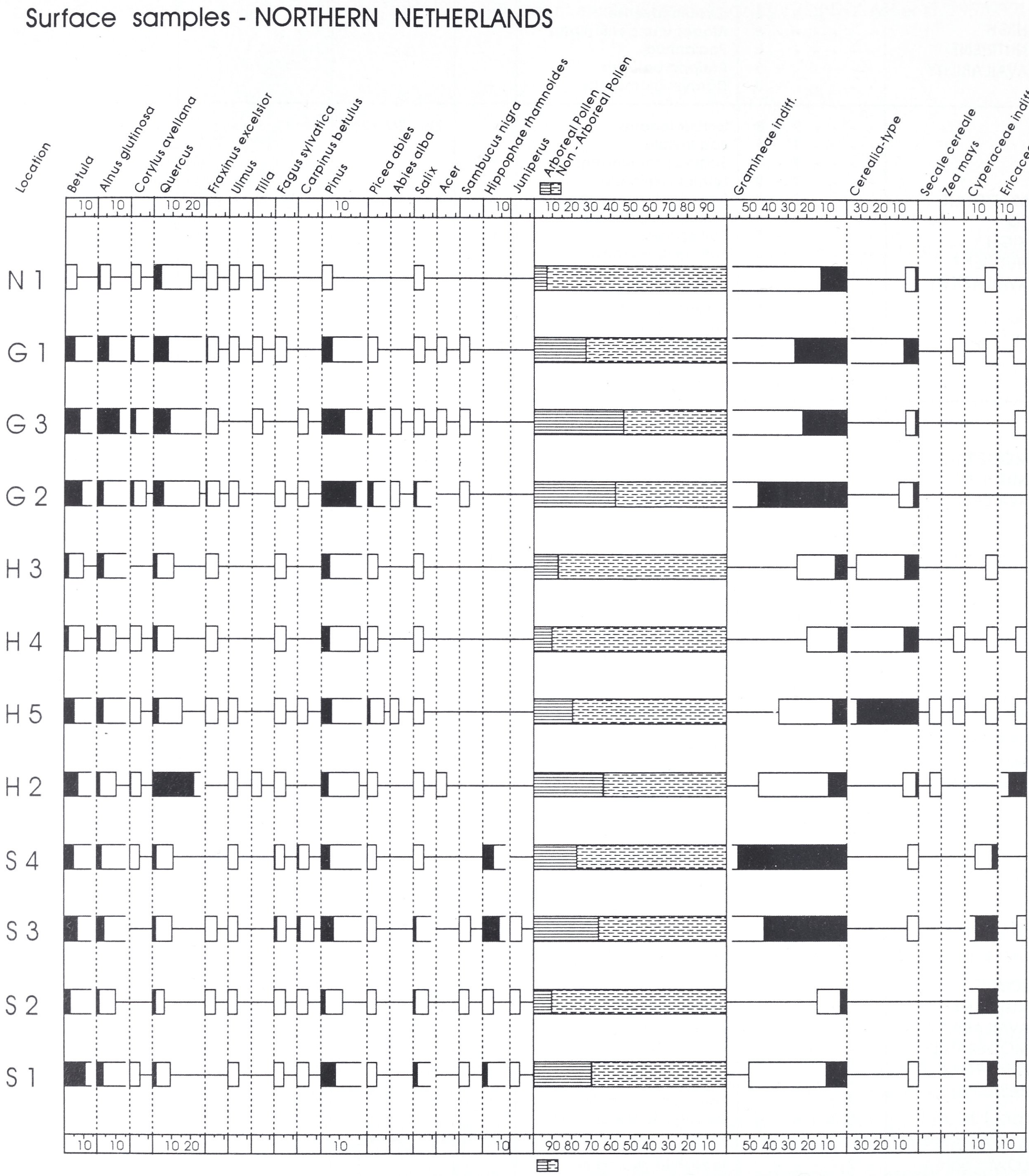
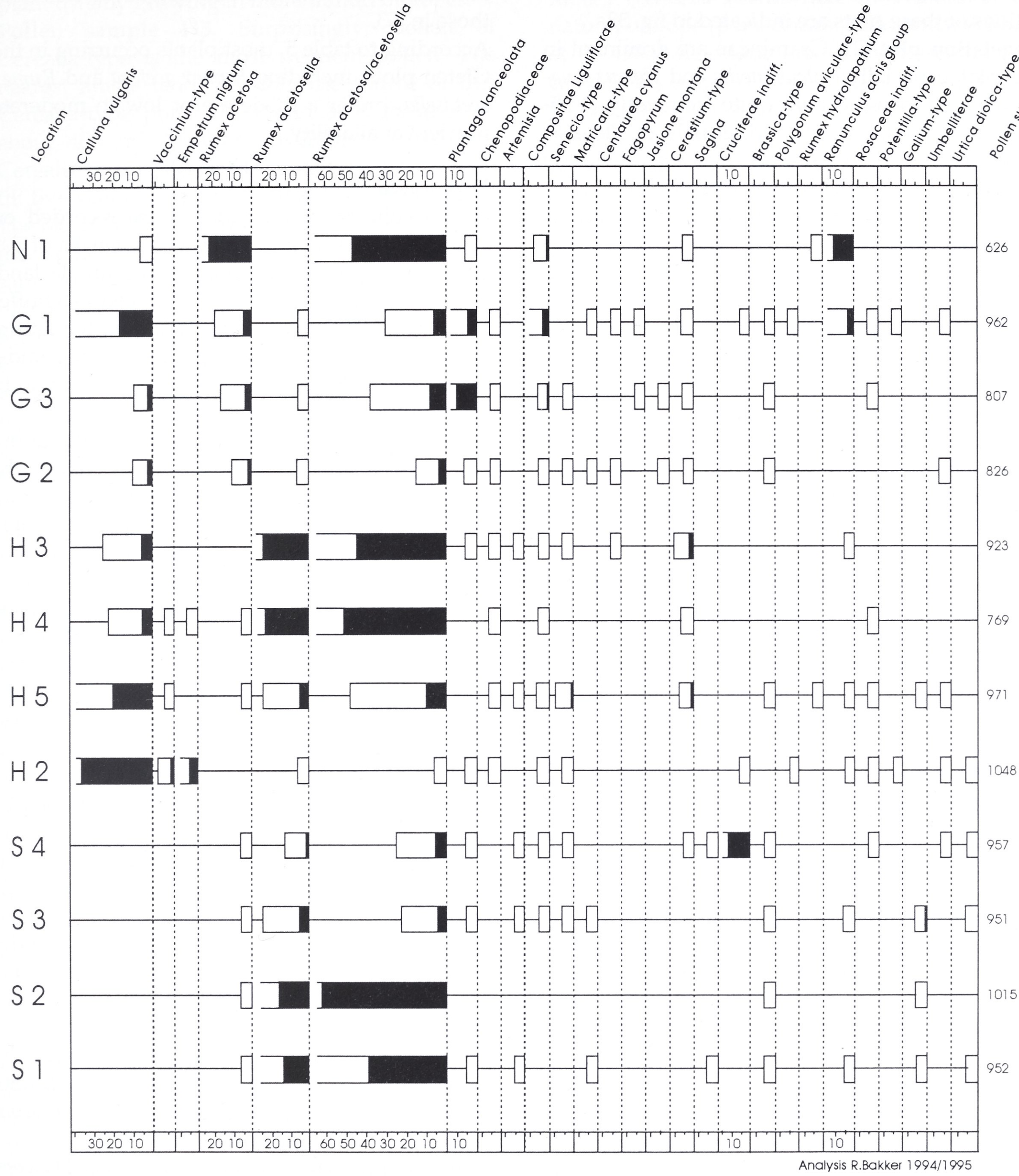


Fig. 33. Surface samples from four locations in the northern Netherlands: N: Nietap, G: Gieten, H: Hijkerveld, S: Schiermonnikoog.


Location
Calluna vulgaris
Vaccinium-type
Empetrum nigrum
Rumex acetosa
Rumex acetosella
Rumex acetosa/acetosella
Plantago lanceolata
Chenopodiaceae
Artemisia
Compositae Liguliflorae
Senecio-type
Matricaria-type
Centaurea cyanus
Fagopyrum
Jasione montana
Cerastium-type
Sagina
Cruciferae indiff.
Brassica-type
Polygonum aviculare-type
Rumex hydrolapathum
Ranunculus acris group
Rosaceae indiff.
Potentilla-type
Galium-type
Umbelliferae
Urtica dioica-type
Pollen sums
N 1
G 1
G 3
G 2
H 3
H 4
H 5
H 2
S 4
S 3
S 2
S 1
626
962
807
826
923
769
971
1048
957
951
1015
952
30 20 10
20 10
20 10
60 50 40 30 20 10
10
10
10
Analysis R.Bakker 1994/1995

Gieten
In the direct neighbourhood of the Gietsenveentje, near the village of Gieten, three vegetation plots were recorded on June 9th, 1994 in moderately nutrient-rich grassland, which had not been manured for the last 20 years. The locations of these plots are indicated in fig. 32a.
Vegetation plot G1. Gramineae are dominant in this plot, especially *Holcus mollis* and *Holcus lanatus*. *Rumex acetosa* occurs quite frequently (12.5-25% cover). Also a few individuals of *Plantago lanceolata* occur. The absence of *Rumex acetosella* and the common presence of *Ranunculus acris/repens* in G1 point to more nutrient-rich conditions compared to the other Gietsenveentje plots.
Pollen sample G1. In the pollen picture, Gramineae play a dominant role too. The *Rumex* types are scarcely observed: *Rumex acetosa* occurs more frequently than *Rumex acetosella*. The occurrence of pollen of *Ranunculus acris* group and *Plantago lanceolata* corresponds to the plot data. Pollen of *Calluna vulgaris* occurs very frequently in the sample, although practically no Ericaceae are found in the wide surroundings of the plots. Possibly this Ericaceae pollen is of an older date, probably of the time that heathland dominated the landscape in this area (the early 20th century). Although the aim was to collect the moss samples without any substrate (see IV.9), it is not impossible that some soil still stuck to the moss samples. Soil could be a possible source of subfossil heather pollen (BOTTEMA 1995).
Vegetation plot G3. Gramineae are again dominant: *Festuca ovina* and again *Holcus lanatus*. *Rumex acetosa* and *Rumex acetosella* occur in equal numbers (each 5-12.5% cover). The frequent occurrence of *Stellaria graminea* and *Campanula rotundifolia* is conspicuous. *Plantago lanceolata* occurs in relatively large numbers.
Pollen sample G3. G3 shows higher AP values than G1, caused by higher percentages of *Betula*, *Alnus*, *Quercus*, *Pinus* and *Picea*. The first three occur in the direct surroundings of the Gieten vegetation plot locations, for example in the nearby Gietsenveentje (fig. 32a; see also VI.2). *Calluna vulgaris* occurs very sparsely in this sample. Values of *Rumex acetosa* as well as *Rumex acetosella* are low. Just as in the vegetation plot, *Plantago lanceolata* reaches a relatively high value.
Vegetation plot G2. Gramineae are even more dominant than in G1 and G3: *Festuca ovina*, *Festuca rubra*, *Anthoxanthum odoratum* and *Holcus lanatus* together cover almost 100% of the plot! *Rumex acetosa* and *Rumex acetosella* occur in very low numbers (each less than 25 individuals).
Pollen sample G2. Gramineae are dominant by far, correlating to the plot data. Some trees, especially *Betula*, *Pinus* and *Picea*, reach relatively high values. The last two occur about 200 m east of the Gietsenveentje. Values of *Rumex acetosa* and *Rumex acetosella* are very low, even less than those in G3.
According to table 5, most plants occurring in the Gieten plots, including *Rumex acetosa* and *Rumex acetosella*, prefer a moderate or low to moderate nutrient availability.

Hijkerveld
In the Hijkerveld, four plots were recorded on May 31st, 1994 on a transect with a length of 500 m. This transect leads from former arable land, which for the last five years has served as a buffer zone between present arable land and the nature reserve Hijkerveld, to an oak grove in the midst of heather. The locations of these plots are indicated in fig. 32b.
Vegetation plot H3. *Rumex acetosella* is the dominant species (12.5-25% cover), together with the grasses *Aira praecox*, *Holcus lanatus* and *Festuca ovina*. The presence of two species which strongly prefer nutrient-rich soils, *Taraxacum officinale* and *Cirsium arvense*, is of particular interest.
Pollen sample H3. As might be expected, pollen of *Rumex acetosella* and *Rumex acetosa/acetosella* is dominant. Together these two types comprise nearly 70% of the pollen sum. In spite of the abundance of Gramineae in the plot, only small quantities of Gramineae pollen are observed in the pollen sample. This can be explained possibly by the fact that the most frequent grass in the plot is *Aira praecox*, a very small species which had finished flowering by the time the sample was collected. Pollen of *Cerastium*-type most probably originates from *Cerastium semidecandrum*, occurring in the plot. Pollen of Cerealia-type, originating from nearby arable land, occurs quite frequently. The AP plays a minor role in this sample.
Vegetation plot H4. The plot is characterized by an absolute dominance of *Rumex acetosella* (50-75% cover). *Aira praecox* and *Cerastium semidecandrum* occur frequently.
Pollen sample H4. The pollen content of H4 very much resembles that of H3. *Rumex acetosella* and *Rumex acetosa/acetosella* comprise more than 70% of the pollen sum.
Vegetation plot H5. This plot is located relatively close to the heather. Surprisingly, the plot is dominated by a species which strongly prefers nutrient-rich soils, *Cirsium arvense*. Grasses

usually occurring on less nutrient-rich soils, *Aira praecox* and *Agrostis capillaris*, are quite frequent. *Rumex acetosella* occurs in fairly low quantities (less than 100 individuals). Also specimens of *Rorippa palustris* were observed in this plot, a plant usually growing in more humid biotopes.

Pollen sample H5. Surprisingly, pollen of Cerealia-type is the most frequent pollen. The nearest arable land, possibly the source of this Cerealia-type pollen, is found at a distance of about 400 m. Another possibility is that this Cerealia-type pollen is of greater age, because up till five years ago, this area had been arable land. The old Cerealia-type pollen could originate from the soil, which possibly stuck to the moss samples used for surface sample analysis. The high values of *Calluna vulgaris* are less surprising, because heather occurs at a distance of about 80 m. The most frequent plants in the plot are *Cirsium arvense* and *Agrostis capillaris*. The pollen types that these plants produce, *Cirsium*-type and Gramineae, respectively, do not occur at all (*Cirsium*-type) or occur in low quantities (Gramineae) in the pollen sample. This can be possibly explained by the fact that *Cirsium arvense* and *Agrostis capillaris* were not flowering at the time that the vegetation plots were recorded.

Vegetation plot H2. This plot shows a vegetation completely different from the other Hijkerveld plots: it is recorded in an oak grove with an estimated age of 30 years in the midst of heather. Oak trees (*Quercus robur*) dominate this plot. On the forest floor, *Festuca ovina* is the most common species. *Rumex acetosella* occurs very sporadically.

Pollen sample H2. Ericaceae pollen is dominant: *Calluna* as well as Ericaceae indiff. reach maximum values. *Empetrum nigrum* also occurs quite frequently. As might be expected, *Quercus* is the dominant AP type. It is remarkable that the value of *Calluna vulgaris* is twice as high as the *Quercus* value, although the nearest heather plants occur at a distance of about 50 m. Possibly, the Ericaceae pollen is again of an older date: before the oak grove was planted, heather occurred at this location. In spite of the abundance of *Festuca ovina*, only low quantities of Gramineae pollen are observed.

According to table 5, some plants occurring in the Hijkerveld plots prefer a high or moderate to high nutrient availability, while other plants, including *Rumex acetosella*, prefer a low or low to moderate nutrient availability. Because this area has not been manured for five years, the plants of the latter category will get the upper hand in the future.

Schiermonnikoog

On the island of Schiermonnikoog, four plots were recorded on June 20th, 1995 in dune and salt-marsh vegetation types in which *Rumex acetosella* plays an important role. It is assumed that *Rumex acetosella* occurs here in a more or less natural biotope (pers. comm. S. Bottema; WEEDA et al. 1985). The locations of the plots are indicated in fig. 32c.

Vegetation plot S4. *Rumex acetosella* (12.5-25% cover) and *Festuca rubra* dominate. This plot was recorded next to a cycle track (Joh. de Jongpad) in a salt-marsh area. Probably sand was supplied for the construction of this track. This could explain the presence of species normally not growing in salt marshes, including some species pointing to disturbance: *Cirsium arvense, Trifolium repens* and *Bromus hordeaceus*. These species are absent in the other Schiermonnikoog plots.

Pollen sample S4. Gramineae are dominant by far. Surprisingly, pollen of *Rumex acetosella* and *Rumex acetosa/acetosella* is scarcely observed. Cruciferae pollen reaches a maximum value. Probably this pollen originates from *Cochlearia danica*, a typical coastal species, occurring in the vegetation plot. Pollen of *Hippophae rhamnoides*, a shrub characteristic of dune areas, dominates the AP. Individuals of *Hippophae rhamnoides* grew near the plot.

Vegetation plot S3. This plot is dominated by species growing predominantly on nutrient-rich soils, especially *Holcus lanatus*, as well as species growing predominantly on nutrient-poor soils, especially *Aira praecox, Carex arenaria* and *Luzula campestris*. *Rumex acetosella* occurs quite frequently (12.5-25% cover).

Pollen sample S3. Although the vegetation of plots S3 and S4 differs widely, the pollen picture of the two pollen samples is quite similar: Gramineae dominate, *Rumex acetosella* and *Rumex acetosa/acetosella* occur sparsely. In sample S3, the AP type *Hippophae rhamnoides* reaches higher values than in sample S4. Cyperaceae reach a maximum value in S3. Most probably this pollen originates from *Carex arenaria*, a very common species in and just outside the vegetation plot.

Vegetation plot S2. The plot is dominated by species predominantly growing on nutrient-poor soils, especially *Carex arenaria, Festuca ovina* and *Luzula campestris*. *Rumex acetosella* occurs less frequently than it does in plots S3 and S4 (5-12.5% cover).

Pollen sample S2. *Rumex acetosella* and *Rumex acetosa/acetosella* are dominant by far. Together they comprise more than 75% of the pollen sum!

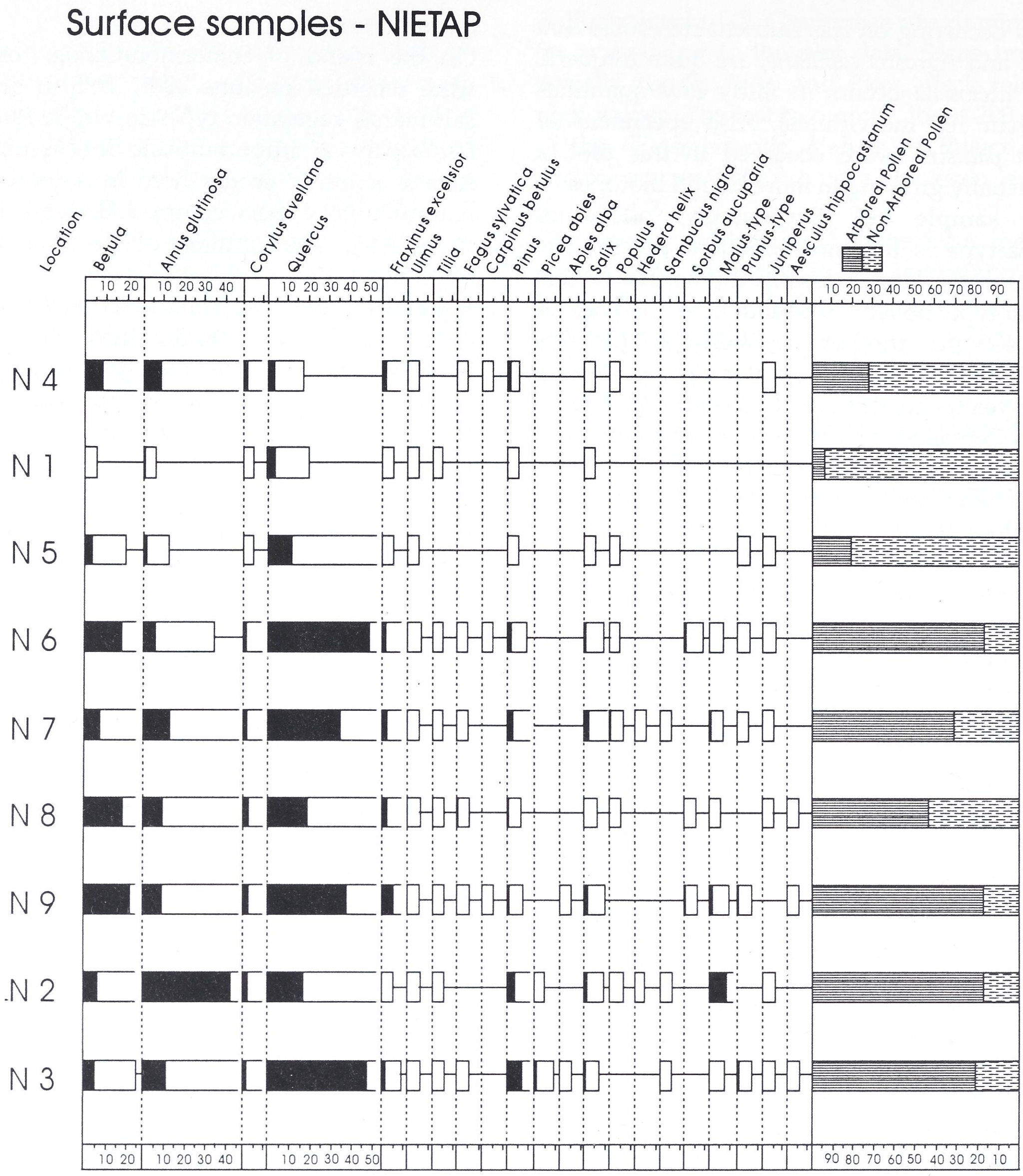
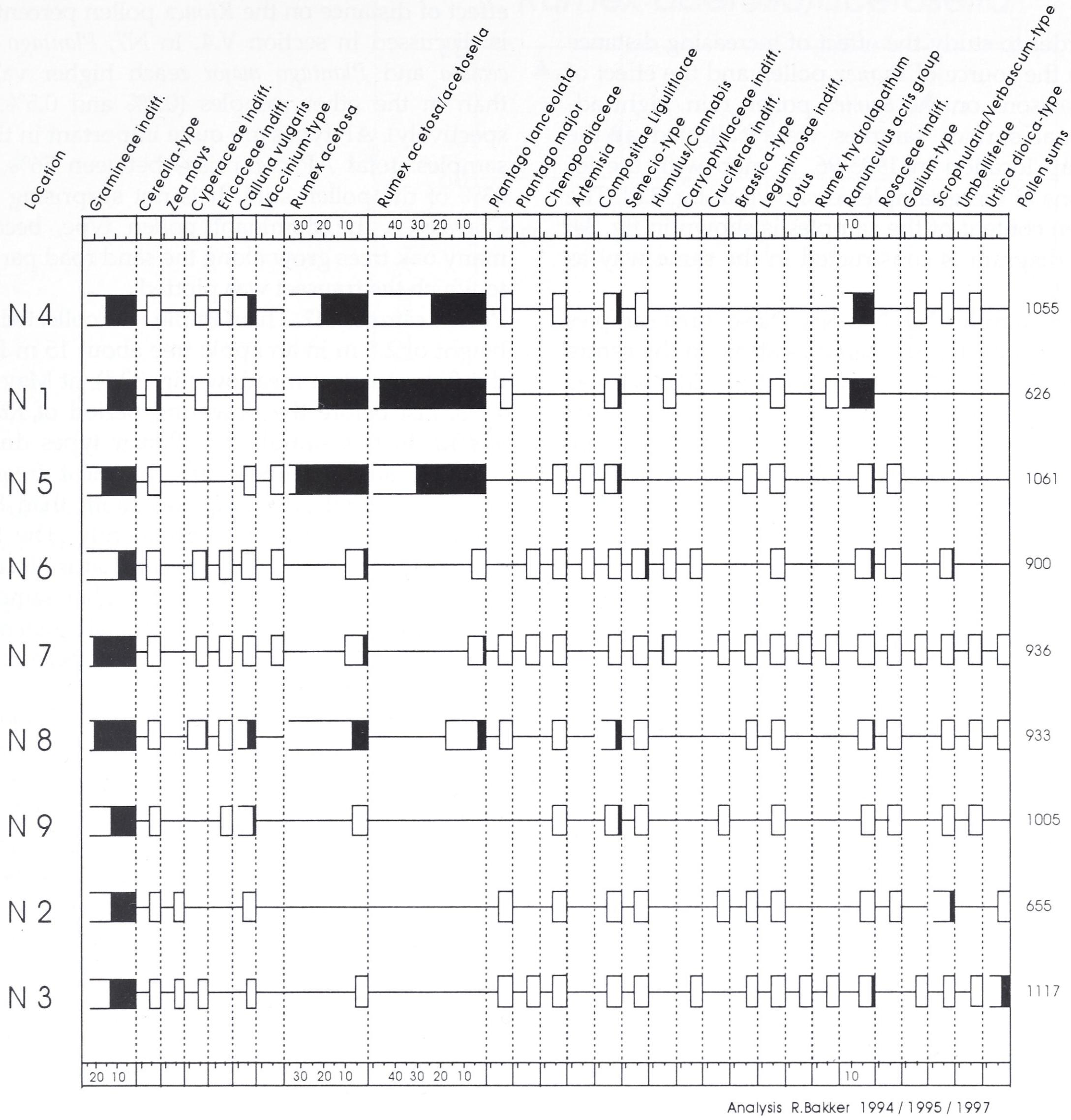


Fig. 34. Surface samples from Nietap.

Gramineae pollen scarcely occurs. This corresponds to the plot data: in S2, Gramineae reach the lowest cover of all twelve plots. The frequently occurring Cyperaceae pollen again seems to originate from *Carex arenaria*, a species which is very common in the plot. Although the sample was taken on a dune top, very few regional pollen seems to occur in the sample. The AP types, of which most are regional because almost no trees occur in the neighbourhood, make up only 10 % of the pollen sum.

Vegetation plot S1. In this plot, recorded in a dune valley, a very species-rich dune vegetation occurs. It is by far the richest of the twelve recorded plots: as many as 24 species were observed. Concerning the dominant species, plot S1 resembles plot S2. *Rumex acetosella* occurs less in S1 than in S2 (< 5% cover, more than 100 individuals); *Holcus lanatus* occurs more often in S1 than in S2. In S1, a few rare species are observed, predominantly growing on nutrient-poor soils: *Filago minima* and the fern *Ophioglossum vulgatum*.

Pollen sample S1. Although in general the pollen picture of S1 resembles the pollen picture of S2, there are also some differences. *Rumex acetosella*,



Rumex acetosa/acetosella and Cyperaceae occur less frequently in sample S1 than in sample S2. This corresponds to the vegetation plot data: in plot S1, *Rumex acetosella* and *Carex arenaria* occur less frequently than in plot S2. Also a few pollen grains of *Rumex acetosa* are observed - just as in the three other Schiermonnikoog samples. Gramineae pollen occurs more frequently in sample S1 than in sample S2; it probably originates from *Holcus lanatus* and *Festuca ovina.*

Some AP types reach relatively high values, especially *Betula, Salix* and *Pinus*. The first two occur within about 20 m from the plot, but the nearest *Pinus* trees grow at a distance of 1 km! According to table 5, some plants occurring in the Schiermonnikoog plots prefer a moderate to high nutrient availability; most plants however, including *Rumex acetosella*, prefer a low or low to moderate nutrient availability.

V.3.2 Surface samples from Nietap

In order to study the effect of increasing distance from the source of *Rumex* pollen and the effect of the seasons on the *Rumex* pollen rain, eight additional surface samples were collected at the Nietap location in 1995-96. A map with the locations of these samples is shown in fig. 32d. The pollen content of the samples is shown in fig. 34. This diagram is constructed in the same way as fig. 33.

Pollen samples N4, N1, N5. These three samples were collected at the same location, in the centre of the *Rumex acetosa* meadow (fig. 32d). N4 was collected on April 28th, 1996, a few weeks before *Rumex acetosa* begins to flower. N1 and N5 were collected on June 9th, 1994 and June 7th, 1996, respectively, at the height of the flowering period of *Rumex acetosa*. Pollen of *Rumex acetosa* and *Rumex acetosa/acetosella* dominates: in N1 and N5 these two types together make up more than 60%; in N4, their combined percentages are significantly lower, about 45%. Pollen of Gramineae and *Ranunculus acris* group occurs frequently. This is not surprising, because different grass species and *Ranunculus acris/repens* occur massively in the meadow. It is conspicuous that *Ranunculus acris* group scarcely occurs in N5. Pollen of Compositae Liguliflorae, for the larger part originating from *Taraxacum officinale*, occurs in all three samples. Although different tree species grow within 25 m of the meadow, the total AP in the three samples always is less than 30%. This must be a relative effect: because at this location the local *Rumex* types totally dominate the pollen picture, the arboreal pollen becomes relatively less important. A consequence of this is that AP types should become more important outside the flowering season of *Rumex acetosa*: N4 indeed has the highest AP percentage of the three samples.

Pollen samples N6, N7, N8, N9. These four samples form a transect, together with N5; they are located at ca. 25 m, ca. 50 m, ca. 75 m and ca. 100 m from the *Rumex acetosa* meadow (fig. 32d). They were collected on June 7th, 1996, at the height of the flowering season of *Rumex acetosa*. These four samples can be correlated quite well, but their pollen content differs widely from that of the previous three samples. In samples N6-N9, the values of the *Rumex* types are very low. In N8, *Rumex acetosa* and *Rumex acetosa/acetosella* make up nearly 10%. This pollen most probably originates from the few individuals of *Rumex acetosa*, occurring at the N8 sample location. The effect of distance on the *Rumex* pollen percentage is discussed in section V.4. In N7, *Plantago lanceolata* and *Plantago major* reach higher values than in the other samples (0.3% and 0.5%, respectively). AP types are quite important in these samples: total AP comprises between 56% and 83% of the pollen sum. It is not surprising that *Quercus* is the dominant pollen type, because many oak trees grow along the sand road parallel to which the transect was plotted.

Pollen sample N2. This sample was collected at a height of 2.5 m in an apple tree about 15 m from the *Rumex acetosa* meadow (fig. 32d), at May 5th, 1995, just before the flowering period of *Rumex acetosa*. In this sample, the *Rumex* types do not occur at all! Gramineae are the most frequent NAP. The total AP comprises more than 80%. *Alnus* pollen occurs most frequently. The high percentage of *Malus*-type pollen naturally originates from the apple tree. At a higher sampling location, the influence of regional pollen increases: *Pinus* and *Picea* reach higher percentages here than in the previous samples.

Pollen sample N3. This sample was collected at a height of 3 m in the roof gutter of the home of H. Woldring, about 40 m from the *Rumex acetosa* meadow (fig. 32d), in January 1995. In total, only three pollen grains of the *Rumex* types were observed. Gramineae dominate the NAP. Although *Urtica dioica*-type nearly never reaches high percentages in surface samples from moss polsters (SPIEKSMA & BOTTEMA 1989), this type reaches a maximum value of 3.3% in sample N3. *Quercus* by far dominates the AP. The regional types *Pinus* and *Picea* reach higher percentages than they do in sample N2.

V.4 Using the surface-sample study for the interpretation of the subfossil pollen diagrams

First some remarks will be made about the biotopes of *Rumex acetosa* and *Rumex acetosella* on the basis of the vegetation-plot data. Then the representation of *Rumex acetosa* and *Rumex acetosella* in surface samples will be discussed using the surface-sample data. Finally, the use of this evidence for the reconstruction of past biotopes of *Rumex acetosa* and *Rumex acetosella* from subfossil pollen diagrams will be discussed.

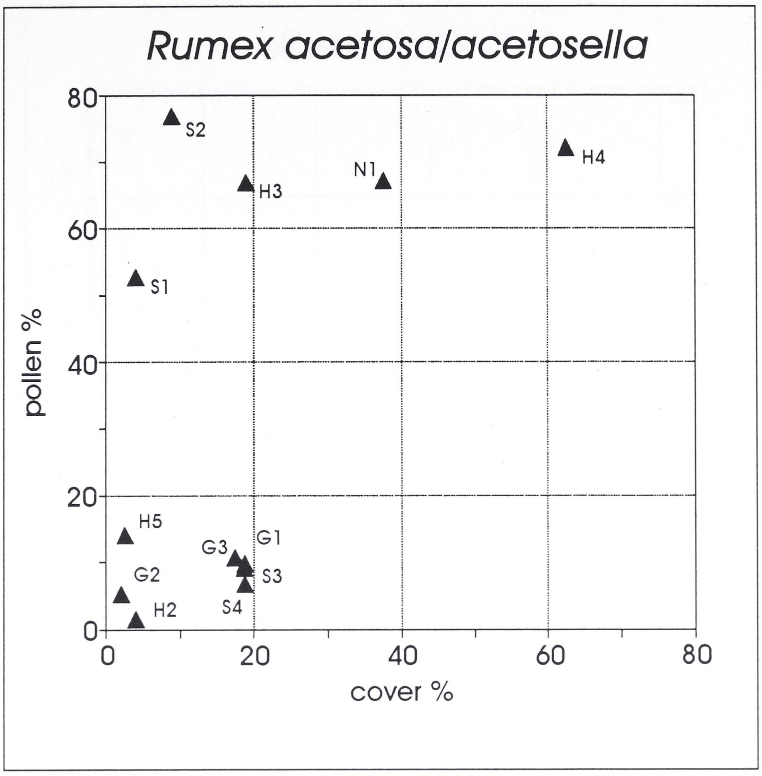


Fig. 35. The total cover percentage of *Rumex acetosa* and *Rumex acetosella* in each vegetation plot, plotted against the total pollen percentage of the *Rumex* types in each corresponding surface sample collected from the centre of the vegetation plot.

Biotopes of *Rumex acetosa*

Brooksides and light spots in the forest are the natural biotopes of *Rumex acetosa* (WEEDA et al. 1985). Nowadays, *Rumex acetosa* occurs for the larger part in strongly human-influenced biotopes. The vegetation plots with *Rumex acetosa* (N1, G1-G3) are all recorded in grassland with a moderate to high availability of nutrients. In these grasslands, the growth conditions for *Rumex acetosa* are optimal. There it often occurs together with *Ranunculus acris/repens* and *Plantago lanceolata*.

Biotopes of *Rumex acetosella*

Leached dune sand and sand drifts are the most important natural biotopes of *Rumex acetosella* (WEEDA et al. 1985). The Schiermonnikoog vegetation plots S1 and S2 (table 5), characterized by a large number of species and by species growing optimally on nutrient-poor soils, represent one of the most natural biotopes of *Rumex acetosella*. The vegetation of the Hijkerveld plots H3 and H4, located in former arable land, shows similarities to the vegetation of plots S1 and S2 (table 5): in all four plots, *Holcus lanatus*, *Festuca ovina* and *Rumex acetosella* are among the most frequent species. There are also some differences: *Taraxacum officinale*, *Cerastium semidecandrum* and *Aira praecox* are present only in H3/H4; *Luzula campestris* and *Carex arenaria* are present only in S1/S2. The pollen content of the Schiermonnikoog samples S1/S2 is very similar to the pollen content of the Hijkerveld samples H3/H4 (fig. 33).

Apparently, optimal growth conditions for *Rumex acetosella* occur in former arable land (plots H3-H5), because the abiotic and/or biotic conditions there resemble the conditions in at any rate one natural biotope: leached dune sand (plots S1-S4). *Rumex acetosella* does not occur at all (plots N1, G1) or only sporadically (plots G3, G2) in grassland with a moderate to high availability of nutrients. *Rumex acetosella* also occurs only sporadically on soils with a very low nutrient availability (plot H2).

Effect of local *Rumex* on the *Rumex* pollen percentage

The influence of the local vegetation on the pollen picture of surface samples can be studied with the help of diagrams in which the cover percentage of a species or group of species in a Braun-Blanquet vegetation plot (2 x 2 m) is plotted against the pollen percentage of that species or group of species in a surface sample collected in the centre of the vegetation plot (EVANS & MOORE 1985). Two such diagrams

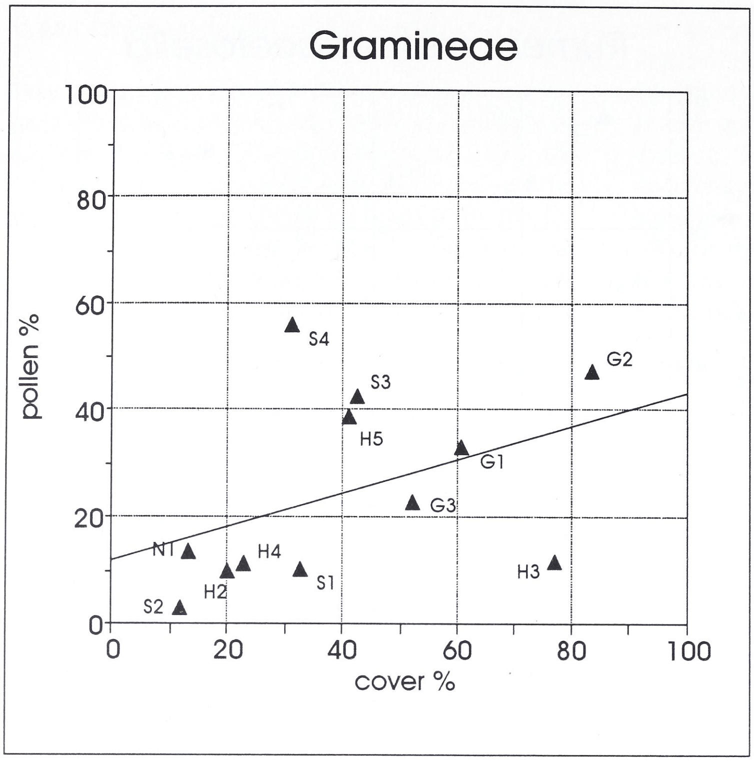


Fig. 36. The total cover percentage of Gramineae in each vegetation plot, plotted against the pollen percentage of Gramineae in each corresponding surface sample collected from the centre of the vegetation plot.

have been drawn, using the data of table 5 and fig. 33: one for *Rumex acetosa/acetosella*, and, for general comparison, one for Gramineae.

In the *Rumex acetosa/acetosella* diagram (fig. 35), the total cover percentages of *Rumex acetosa* and *Rumex acetosella* in each vegetation plot (x-axis) were plotted against the total pollen percentages of the *Rumex* types (*Rumex acetosa, Rumex acetosella* and *Rumex acetosa/acetosella*) in each corresponding surface sample (y-axis). When most of the pollen originates from vegetation in the plot, the correlation between the two variables is expected to be linear (PRENTICE 1982). In the *Rumex acetosa/acetosella* diagram, the correlation is certainly not linear. This probably means that most of the *Rumex* pollen originates from outside the vegetation plots. It has to be emphasized that many factors can influence the correlation between vegetation cover and pollen percentage, for example the ratio between male and female plants, the number of flowering plants, the homogeneity of the vegetation, etc.

A conclusion that may be relevant to the interpretation of the subfossil pollen diagrams is that when the *Rumex* pollen percentage is less than 10% (this is always so in the subfossil pollen diagrams), the **local** cover percentage of *Rumex* never exceeds 20%. Of course, in this estimate the effect of distance, which will be discussed below, is not included.

In the Gramineae diagram (fig. 36), the total cover percentages of all grasses in each vegetation plot (x-axis) have been plotted against the pollen percentage of Gramineae in each corresponding surface sample (y-axis). In this diagram, the correlation is more or less linear. This means that most of the Gramineae pollen originates from vegetation in the plot. A linear regression line was computed for the data in which

$$y = a + bx$$

where $a = 12$ and $b = 0.32$.

This regression line has been drawn in the diagram (fig. 36). (This diagram closely resembles fig. 79 in EVANS & MOORE 1985.)

A large difference between the *Rumex acetosa/acetosella* diagram and the Gramineae diagram is that the Gramineae pollen percentage gives a more or less reliable picture of the local vegetation cover, while the *Rumex* pollen percentage largely represents extra-local (regional?) vegetation. Tinsley & Smith (1974, 564) had already noted that Gramineae pollen in surface samples closely reflects the surrounding vegetation.

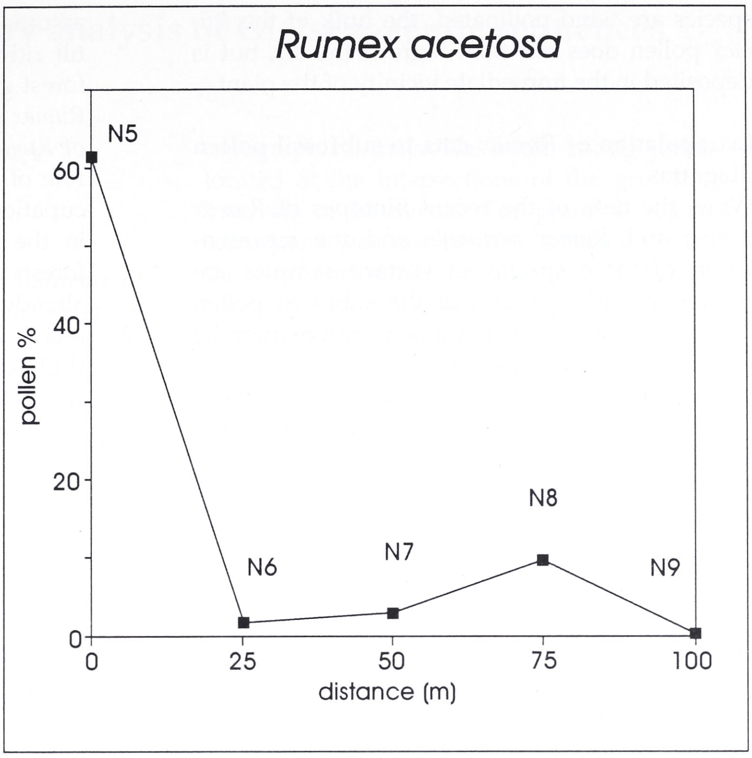


Fig. 37. The total pollen percentage of the *Rumex* types in surface samples, collected at distances of 0, 25, 50, 75 and 100 m from the *Rumex acetosa* meadow at Nietap.

Effect of distance on the *Rumex* pollen percentage

The effect of distance on the pollen percentage of *Rumex acetosa* is studied with the help of pollen samples N5-N9, which were collected along a transect of about 100 m (fig. 34). In fig. 37, the distance from the *Rumex acetosa* meadow at Nietap is plotted against the total pollen percentages of *Rumex acetosa* and *Rumex acetosa/acetosella* (it is assumed that the pollen of *Rumex acetosa/acetosella* originates from *Rumex acetosa*, because no specimens of *Rumex acetosella* occur in the neighbourhood). The samples on the transect do not show a gradient of gradually decreasing *Rumex* values: even in sample N6, only about 25 m from the *Rumex acetosa* meadow, the values of the two *Rumex* types are reduced to a few percent. The other samples also show low values of the *Rumex* types. A conclusion which may be drawn from these five samples is that when the two *Rumex* types reach a total pollen percentage between 1 and 10%, considerable amounts of *Rumex* plants occur within 25 m of the sample location. Data of Caseldine & Gordon (1978, fig. 4) show the same picture: outside areas where *Rumex acetosa* occurs, the percentage of *Rumex* pollen nowhere reaches values of more than 1%.

Effect of the seasons on the *Rumex* pollen percentage

Seasonal effects on the *Rumex* pollen rain were studied with the help of surface samples N2-N4, which were collected in different times of year (fig. 34). Although it is not assumed that the modern pollen content of a moss sample covers only one year or less (BRADSHAW 1981; BOTTEMA 1995), the results of the *Rumex* study indicate that pollen deposited in the last months before sampling plays the most important role in the pollen picture: the *Rumex* values of a sample collected in the *Rumex acetosa* meadow a month before the flowering period of *Rumex acetosa* (N4) are 15% lower than the *Rumex* values of samples collected at the same location in the flowering period (N1, N5). In two other samples, collected at distances of 15 and 40 m from the *Rumex acetosa* meadow outside the flowering period of *Rumex acetosa* (N2, N3), almost no *Rumex* pollen occurs. These two samples were collected at a height of 2.5 and 3 m, respectively; of course, the height of the sample location is also a factor which affects the pollen picture: at a higher location the influence of regional pollen increases.
Not much *Rumex* pollen seems to be deposited outside the flowering period. Although *Rumex*

species are wind-pollinated, the bulk of the *Rumex* pollen does not float high in the air, but is deposited in the immediate vicinity of the plant.

Extrapolation of *Rumex* data to subfossil pollen diagrams

When the data of the recent biotopes of *Rumex acetosa* and *Rumex acetosella* and the representation of these species in surface samples are combined with the data of the subfossil pollen diagrams, it should be possible to reconstruct the former biotopes of these species.

When pollen of *Rumex acetosa* occurs in very small quantities (< 1%), in combination with low Gramineae percentages, and **without** typical culture indicators, notably *Plantago lanceolata*, this pollen originates most probably from *Rumex acetosa* in its natural biotope: brooksides and light spots in the forest.

When pollen of *Rumex acetosa* occurs **in combination with** relatively large quantities of Gramineae, *Plantago lanceolata* and sometimes *Ranunculus acris* group, this pollen probably originates from *Rumex acetosa* in grass-rich vegetation with a moderate to high availability of nutrients (cf. plot G1-G3). The existence of grass-rich vegetation types points to stock keeping.

In surface-sample diagrams of Tinsley & Smith (1974, fig. 4) and Caseldine & Gordon (1978, figs. 2-3) high values of *Rumex*-type (they did not separate *Rumex acetosa* and *R. acetosella*) coincide with high values of Gramineae. The surface samples concerned were collected in nutrient-rich pastures where *Rumex acetosa* occurred. This indicates that the *Rumex* pollen originated from *Rumex acetosa*. These results confirm that the combination of relatively high values of Gramineae and *Rumex acetosa* in pollen diagrams points to grass-rich vegetation with a moderate to high availability of nutrients.

The natural biotopes of *Rumex acetosella*, dune valleys and sand drifts, do not occur in the wide surroundings of the Gietsenveentje (cf. plot S1-S4). When pollen of *Rumex acetosella* is observed in the Gietsenveentje diagrams, it must originate from one of the following, man-made biotopes:

1. areas where dry deciduous and pine forests have been cut (WEEDA et al. 1985). It is assumed that when the virgin forests on the till ridges were cut, the soil on which this forest grew was still too rich in nutrients for *Rumex acetosella* to grow. Hence, this biotope of *Rumex acetosella* most probably played no role of importance during the Neolithic Occupation Period. It gained in importance only in the last few centuries, when secondary forests, planted by man and growing on soils already poor in nutrients, were cut.
2. arable land with *Secale* on acid sandy soils (BEHRE 1981). *Rumex acetosella* grew as a weed among the *Secale* plants. Nowadays, this biotope of *Rumex acetosella* has practically disappeared. In the neighbourhood of the Gietsenveentje, this biotope was of little importance, because *Secale* pollen is only observed in the very upper part of the Gieten V-A diagram (fig. 56), while pollen of *Rumex acetosella* occurs much earlier.
3. former arable land that has been used for a long period, as a result of which the soil is leached (moderate to low availability of nutrients) (cf. plots H3-H5). Most *Rumex acetosella* pollen in the Gietsenveentje diagrams must originate from this biotope. *Rumex acetosella* pollen often reaches a maximum just before a maximum of Ericaceae pollen. This can be explained as follows: as the already nutrient-poor soils on which *Rumex acetosella* thrives become more and more leached, eventually only Ericaceae can grow on these poor soils: a phase with relatively large quantities of *Rumex acetosella* can be considered a precursor of an Ericaceae phase.

In a surface-sample diagram by Tinsley & Smith (1974, fig. 5) a peak of *Rumex*-type coincides with high values of Ericaceae. The surface sample was collected in a *Calluna*-dominated area where *Rumex acetosella* colonized a small burned patch within 2 m of the sampling point. This indicates that the *Rumex* pollen must originate from *Rumex acetosella*. These results confirm that the combination of relatively high values of Ericaceae (particularly *Calluna*) and *Rumex acetosella* in pollen diagrams points to nutrient-poor soils, which can develop in arable land that has been used for a long period.