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# The effects on arthropods of tree plantation and spontaneous afforestation on former agricultural land near old forests in the Voeren region (Belgium)

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**Abstract**

We present a project to evaluate, by means of different arthropod groups, the effects of spontaneous afforestation, under different management regimes, or by tree plantation on former arable fields and grasslands. The arthropod composition of 15 sites was therefore studied in or nearby three forest complexes in the Voeren region. This paper summarizes the methodologies used and describes the environmental variation, of assumed importance for invertebrate assemblages, between the sites. Besides the possible influence of historical background on the prevailing environmental conditions and arthropod communities, also the differences between plantations and spontaneously developing forest sites were studied. We conclude that, in order to evaluate the effects of afforestation on former agricultural fields in the Voeren region, the scale of the applied environmental analysis has to be based on a preliminary study of the considered arthropod group. If we find a lot of forest specific species we have to analyse different forest complexes separately. The invertebrate taxa most appropriately sampled by pitfalls, i.e. soil-dwelling arthropods (in this study: Carabidae, Araneae, Formicidae, Oniscoidea and Myriapoda), especially react on environmental conditions at soil-level and individual trap-level and to a lesser degree at landscape-(site) level. In addition, several groups with good flying adults (Empididae, Dolichopodidae, Syrphidae, Asilidae, Cerambycidae, Coccinellidae, Orthoptera, Apoidea, and Rhopalocera) will have to be evaluated mainly on the landscape ecological-level. In forthcoming papers detailed results will be presented on several of these arthropod groups.

**Key words**: afforestation, plantation, low density grazing, former arable fields, former grasslands, nature development, environmental variables, Principal Component Analysis, sampling methods, arthropods.

## Introduction

In Western-Europe, Flanders represents one of the most poorly forested regions. The majority of its forests are very small, highly fragmented and irregularly spread (TACK *et al.*, 1993; DEKEERSMAEKER *et al.*, 2001). At present, forest cover in Flanders remains at less than 7% mainly due to intensive agricultural and urban land use (DUMORTIER *et al.*, 2003). Recently, the growing importance of Flemish forest for recreation has largely replaced its former use for wood production or as hunting area. With increasing human population density and continuous loss of forest area in Flanders, the need to enlarge existing forests or create new woodlands, became a high priority policy. After consulting all involved actors, the Flemish government recently decided to provide 10.000 ha of new forest on former agricultural sites between 1994 and 2007, in addition to 10.000 ha of 'ecologically well-selected forest expansion' elsewhere (ANONYMUS, 1996; 2001; VERSTRAETEN *et al.*, 2001). Several beneficial effects for nature are expected from the expansion of forests, but most of these remain to be tested empirically. It is mainly in this research area that our entomological studies are to be situated.

In most cases, the only locations in Flanders that can be transformed into new forests are former grasslands and arable fields. To manage 'ecologically sound forest expansion' several landscape planning criteria have to be considered. First of all, new forests are preferred to be located close to existing ancient forests. Other proposed new forests should connect existing natural areas or act as a buffer against and be in the immediate vicinity of or surrounding densely populated agglomerations. Where possible, spontaneous processes should be encouraged because these are assumed to yield greater natural (floristic) values than transformation by plantation (VERSTRAETEN *et al.* 2001). When plantations are conducted, only autochthonous tree species should be used. Furthermore, plantations are preferably organised in mosaic patterns (different tree species) and alternating with open areas (15% of the total area). Also the original abiotic and structural characteristics of the transformed areas should remain unchanged (e.g. no drainage in wet places).

In order to succeed in ecologically valuable forest expansion, a basic knowledge of the influence on fauna and flora of different afforestion and forest transformation methods is needed. Until now, only little knowledge is available on how these processes can be monitored and, when necessary, adjusted, mainly because afforestion sites in Flanders are scarce and only a recent phenomenon (HERMY, 1985). The Flemish government has therefore launched some projects to find out the most efficient ways of afforestation. Those projects have the aim to determine important environmental variables, the influence of former history and finally the most adequate way to transform former arable fields or grasslands into forest (VERSTRAETEN *et al.*, 2001: VAN UYTVANCK & DECLEER, 2002). A project to evaluate the effects by means of different arthropod groups of spontaneous afforestation under a management regime of year-round low density grazing or intensive summer grazing or by tree plantation on former arable fields and grasslands started early 2003 (TWOL-project AMINAL/B&G/30/2002 project 3). Until now, invertebrates have only very rarely been used to evaluate such great scale transformations for nature development. Very few studies are available in which guidelines can be found on how invertebrate communities react on nature development measures in general and on afforestion in particular (GREENBERG & MCGRANE, 1996; SAMWAYS *et al.*, 1996; PACQUIN & CODERRE, 1997: BROMHAM *et al.* 1999; KOTZE & SAMWAYS, 1999; VASCONCELOS, 1999; MAGURA *et al.*, 2002; WATT *et al.*, 2002).

The aim of this paper is to describe their localisation in the Voeren region and to characterise in detail the different study sites. In this region we had the opportunity to study the arthropod composition of 15 sites in or nearby three forest complexes. The sites differ in former agricultural use (none: ancient forest, former grasslands or cornfields), in age (ancient forest, 6-25 years since let for afforestation) and management (no grazing, low-density year-round or intensive summer grazing). We will try to identify the environmental conditions characteristic for ancient forest and we will compare these with the abiotic and biotic conditions we could observe in the new forests on former agricultural land. Besides the possible influence of historical background on the prevailing environmental conditions and arthropod communities, also the differences between plantations and spontaneously developing forest sites will be studied. In addition, we have here the opportunity to evaluate the possible different effects on the arthropod fauna of low-density year round grazing (8 Galloways on 42 ha) and intensive summer grazing during spontaneous forest succession. This paper presents the methodologies that were used and the environmental variation between the sites, which might be of importance for invertebrate assemblages. In forthcoming papers, we will study several arthropod groups in detail.

## Material and Methods

### *Study area*

The oldest sites in Flanders where afforestation was planned and carried out on former arable fields and grasslands on loamy soils are situated in the Voeren region. In the neighbourhood of two ancient forest relics (the Altenbroek and the Alserbos), relatively large areas of agricultural land were purchased for spontaneous afforestation or plantation of indigenous trees. On small-scale plots different types of trees were planted. In total, 15 sampling sites were selected, including one site in the large Veursbos as external reference plot. The location of all study sites is shown in Figure 1; their historical background and general characteristics are given in Table 1 (partly based on VERSTRAETEN *et al.*, 2001).

### *Investigated entomofauna groups*

Soil surface active fauna was studied in the 15 sites (see Fig. 2). In 11 out of the 15 sites we made an inventory of non-soil dwelling arthropod groups as well, including different families of flies, some Apoidea families, butterflies and ladybirds. In order to evaluate and compare the arthropod fauna, these two different levels have to be considered separately. The groups best sampled by pitfalls, i.e. soil dwelling arthropods, especially react on environmental conditions at soil-level and individual trap-level and to a lesser extent at landscape-(site) level. Soil dwelling groups studied in this project are Carabidae, Araneae, Formicidae, Oniscoidea and Myriapoda.

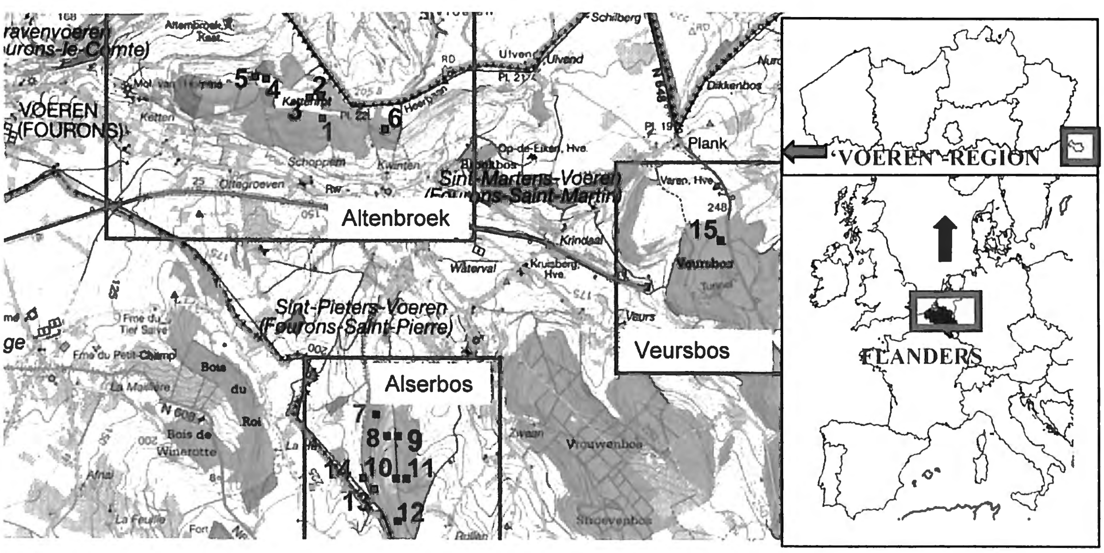


Fig. 1 — The study area in Flanders and location of the 15 sampling sites.

Table 1 — Code, historical background, short description and age of the sampled sites; with * indicating sites only sampled with pitfall traps.

| Site code | Forest complex | Historical background | Characterisation of the site | Forested since |
|---|---|---|---|---|
| VOER01 | Altenbroek | Ancient forest | Ancient oak-birch forest | <1775 de Ferraris |
| VOER02 | Altenbroek | Arable field | Low density grazing by Galloway cows; spontaneous afforestation by willow and birch. | 1996 |
| VOER03 | Altenbroek | Grassland | Low density grazing by Galloways; spontaneous afforestation; not yet shrubs, trees | 1996 |
| VOER04 | Altenbroek | Arable field | Intensive summer grazing; spontaneous afforestation by willow and birch | 1996 |
| VOER05 | Altenbroek | Arable field | Afforestation by plantation of *Quercus robur* | 1989 |
| VOER06* | Altenbroek | Ancient forest | Ancient mixed deciduous forest | <1775 de Ferraris |
| VOER07 | Alserbos | Ancient forest | Ancient oak-birch forest | <1775 de Ferraris |
| VOER08 | Alserbos | Grassland | Afforestation by plantation of birch | 1980 |
| VOER09 | Alserbos | Arable field | Afforestation by plantation of birch | 1980 |
| VOER10 | Alserbos | Grassland | Plantation of *Prunus avium*; patches of spontaneous *Calluna vulgaris* undergrowth | 1985-1990 |
| VOER11 | Alserbos | Arable field | Afforestation of birch | 1980 |
| VOER12 | Alserbos | Grassland | Plantation of *Quercus robur* | 1985-1990 |
| VOER13* | Alserbos | Ancient forest | Ancient mixed deciduous valley forest | <1775 de Ferraris |
| VOER14* | Alserbos | Ancient forest | Ancient mixed deciduous valley forest | <1775 de Ferraris |
| VOER15* | Veursbos | Ancient forest | Ancient oak-beech forest | <1775 de Ferraris |

Additionally, several groups with good flying adults such as Empididae, Dolichopodidae, Syrphidae, Asilidae, Cerambycidae, Apoidea, Coccinellidae, Orthoptera, and Rhopalocera will be evaluated on the landscape level only. Here we call them non-soil-fauna elements although larval stages of many species depend on soil characteristics. These groups are best and were sampled with white water traps and Malaise traps. For these groups, variation in soil and vegetation structure and composition will be analysed at site-level only.

### *Sampling techniques*

Several recent projects, set up to make inventories of different arthropod groups in Flanders, showed that a combination of pitfalls, white water traps and Malaise traps enables us to collect a considerable part of the arthropod fauna (Bonte *et al.*, 2000; De Bakker; *et al.*, 2000; Dekoninck *et al.* 2001; Bonte & Grootaert, 2003). In 11 sites (VOER01-05, in Altenbroek forest complex in St-Martens-Voeren; VOER07-12, Alserbos forest complex in Sint-Pietersvoeren), 3 pitfalls (Fig. 3), 3 white water traps (Fig. 4) and one Malaise trap (Fig. 5) were installed to sample the entomofauna. In four additional reference sites (VOER06, 13-15) three pitfalls were installed. In these additional sites (marked with * in Table 1) other traps were not installed due to time constraints and practical problems to install Malaise traps.

All pitfalls (diameter of 9.5 cm) and white water traps (17x10 cm and 5 cm high) were placed in a row, spaced 3-5 m apart. A 3.5% formaldehyde solution was used as killing and fixation agent and some detergent was added to lower surface tension. The vial in top of the Malaise trap was filled with a 75% alcohol solution. All traps were emptied fortnightly, 12 times from 02-IV-2003 until 08-X-2003, i.e. on 17-IV, 01-V, 14-V, 30-V, 14-VI, 26-VI, 11-VII, 25-VII, 07-VIII, 22-VIII, 19-IX and 08-X.

*Characterisation of the different sampling sites and environmental variables*

At each pitfall in the 15 sites (n=45) the percentage ground covered by each abundant plant species was estimated (Londo-scale on a 2x2 m area) and variation of vegetation height was determined as a measure of vegetation structure. Around each pitfall, we assessed the ground coverage of grasses, herbs, shrubs (< 5 m), trees (> 5 m), leaf-litter, mosses and bare ground. Vegetation height was an average of 30 randomly taken measurements of vegetation height and vegetation structure was the estimated standard deviation. In this paper, we will not consider and analyse vegetation communities as done in floristic studies. Our main focus concerning the impact of vegetation on arthropod fauna will be the structure and the coverage of the different vegetation-layers. For some phytophages, the plant species composition is also of major importance (Pacquin & Coderre, 1997; Majer *et al.* 2003) but for most groups in our study (almost no species-specific phytophages) only vegetation structure and related variables are supposed to have possible importance.

For each site a soil sample being a mixture of three samples, each taken at each pitfall during its installation was analysed for 10 soil characteristics. This resulted in 11 quantitative variables (also C/N was calculated). Some


Fig. 2 — Overview of the sampling sites.

Fig. 3 — Pitfall trap at site VOER01.

Fig. 4 — White water trap at site VOER01.

Fig. 5 — Malaise trap at site VOER01.

other variables such as the distance to open field, the distance to ancient forest (both in m), the amount (mg/kg soil) and type of stones, amount of dead wood, % sunlight reaching the soil and grazing intensity were assessed and used in our multivariate analysis as categorical variables. All variables, and the level at which they were used, are presented in Table 2 and Table 3 (21 quantitative variables and 6 categorical variables).

### *Analyses of the environmental variables*

The major aim of this paper is to extract and summarise the important environmental variation from the measurements at each site. As several of the environmental variables are quantitative and based on different measuring units, they were z-transformed before using them in Principal Component Analysis. PCA is a multivariate

Table 2 — All 21 measured quantitative variables and the level they were used on.

| Measured variables | Codes in PCA | Site-specific species | No site-specific species | |
|---|---|---|---|---|
| | | **At site level: for ancient forests sites and for each forest complex separated** | **At pitfall level: 45 sample units** | **At site level; 11 and 15 sample units** |
| **1) Vegetation characteristics** | | | | |
| Cover of trees | Tree | x | x | X |
| Cover grass layer | Grass | x | x | X |
| Cover herbs | Herbs | x | x | X |
| Cover shrubs | Shrub | x | x | X |
| Cover bare ground | bare gro or soil | x | x | X |
| Cover mosses | Mosses | x | x | X |
| Cover leaf litter | leaf-lit | x | x | X |
| Depth of leaf litter and humus in cm | Humus | | | X |
| Vegetation height in cm | VegH | | | X |
| Vegetation structure in cm | VegStruc | | | X |
| **2) Soil characteristics** | | | | |
| pH(KCL) | pH(KCL) | x | | X |
| pH($H_2O$) | pH($H_2O$) | x | | X |
| Tot. C% | Tot. C | x | | X |
| Tot. N% | Tot. N | x | | X |
| Loss On Ignition 550 °C | LOI.5 | x | | X |
| Loss On Ignition 900 °C | LOI.9 | x | | X |
| Tot. Ca in mg/kg soil | Tot. Ca | x | | X |
| Tot. Mg in mg/kg soil | Tot. Mg | x | | X |
| Tot. Na in mg/kg soil | Tot. Na | x | | X |
| Tot. K in mg/kg soil | Tot. K | x | | X |
| C/N in mg/kg soil | C/N | x | | |

Table 3 — Categorical variables for each site used for bi-plot overlays.

| **Categorical variables n= 15 and 11, site level** | **Categories** |
|---|---|
| Distance to open field: 4 categories | 0= at the edge of open field, 1= <50m, 2= 50-100m and 3=>100m |
| Distance to ancient forest: 4 categories | 0= ancient forest, 1= <50m, 2= 50-100m and 3>100m |
| Dead wood | 0= no dead wood, 1= very little, 2=a little and 3=a lot |
| Amount of light reaching the soil | 0= 0-20%, 1= 20-40%, 2= 40-60% and 3= >60% |
| Grazing | 0= no grazing, 1= low density grazing and 2= intensive summer grazing |
| Stones in the ground | 0= none, 1= few silex, 2=many silex stones and 3=gravel of the Meuse river |

technique that positions samples along orthogonal axes that sequentially explain the greatest amount of inter-sample variation (HAMANN *et al.*, 1998; MCCUNE & GRACE, 2002). We use PCA in an attempt to define suites of interrelated variables, in order to condense or transform our data from 11 (or 15) sites or 45 sampling units (pitfalls) and 21 quantitative variables into a smaller number of composite variables, i.e. the different main axes. PCA-axes can then be used as explanatory variables in future analyses on faunal responses. Calculations were carried out in PC-ORD 4 (MCCUNE & MEFFORD, 1999) with default settings.

To check for the significance of the derived axes, Pearson correlations were calculated. Adopted significance levels are presented in Table 4. The number of significant axes was determined by comparison of the eigenvalues of the axes to those produced by a broken-stick model as done by JACKSON (1993) and suggested by MCCUNE & MEFFORD (1999). Categorical variables were used for DCA overlays and will be used in descriptive parts of other papers. We use them to represent sample units in order to look for trends in DCA diagrams without statistical inference.

## Results

Within a study area – here the Voeren region – a forest complex (for example the Altenbroek) can have a typically environmental composition and maybe also a forest-specific fauna or several typical species. If the latter is the case for an entomofauna group, we have to analyse and compare each forest complex separately. Therefore we will first look if we can detect differences for the considered environmental variables between all ancient forests. We will try to characterise the ancient forest

Table 4 — Adopted significance levels for the 3 different sampling unit levels used.

| | **N number of sampling units** | **Significance level** | **Pearson r** |
|---|---|---|---|
| Pitfall level | 45 | p<0.001 | r>0.47 |
| Site level | 15 | p<0.01 | r>0.64 |
| Site level | 11 | p<0.01 | r>0.73 |

environment in comparison with that the new forests sites within each forest complex. This result will be used in case of an entomofauna group with forest-specific species.

If we do not find any forest-specific species for an entomofauna group, we can analyse and study all sites from the three forest complexes together as done in the second part of this article. The most detailed level of environmental variance we can detect is the variance at pitfall-level, considered to be important for soil arthropod-fauna. At this level we also have the highest number of sampling units; 45 pitfalls spread over 15 sites. If we indeed do not find any forest complex linked species in the studied group, we can look if we can detect trends on a higher level i.e. landscape level (=site level). At this level the analyses were done for all 15 (soil dwelling fauna group) and 11 site (for non-soil dwelling arthropods). For the vegetation and litter characteristics at site level, average values for each set of 3 pitfalls were used.

### *Forest complex specific species present: analysis within each forest complex*

In this part we contrast ancient forest environment with the new forests sites within each forest complex, i.e. we search for values in environmental variables and species which might be linked to each of the two forest complexes. When we observe some forest complex specific species within the entomofauna group studied, we will have to analyze the faunas of the forest complexes separately. In this part we first try to characterize the ancient forests and we will than compare them with the new forests within each forest complex.

– Ancient forests in the Voeren region

*a) Soil composition* (see Table 5)
The first axis in the PCA diagram (Fig. 6) is strong negatively correlated with pH, Loss On Ignition, LOI 550 °C (an estimate of organic matter), C/N and all basic cations ($Na^{+}$, $Mg^{2+}$, $Ca^{2+}$ and $K^{+}$). In the PCA diagram we can see 2 groups: group A on the left (VOER06, VOER13 and VOER14, all valley forests) and group B on the right (VOER01, VOER07 and VOER15, all forests on the plateaus). In group A the actual pH (pH-$H_2O$) ranges from 5.97 to 6.19, while in group B the range of pH-$H_2O$ is 5.10-5.47. In the valley forests we find a

Table 5 — Soil characteristics of all ancient forest sites.

| Site | Soil variables | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH(KCl) | pH(H2O) | Tot C | Tot N | L.O.I. 550 °C | L.O.I. 900 °C | Tot.Ca | Tot.Mg | Tot.Na | Tot.K | C/N |
| Voer07 | 0,59 | 5,10 | 6,95 | 0,94 | 10,80 | 0,42 | 54,59 | 28,18 | 8,12 | 51,70 | 7,39 |
| Voer01 | 0,44 | 5,21 | 7,55 | 1,09 | 13,16 | 0,43 | 53,06 | 35,58 | 11,25 | 66,90 | 6,93 |
| Voer15 | 0,54 | 5,47 | 9,27 | 0,90 | 13,95 | 0,61 | 37,51 | 49,27 | 11,21 | 108,12 | 10,30 |
| Voer14 | 3,56 | 6,19 | 11,91 | 0,86 | 19,20 | 13,65 | 5305,20 | 78,28 | 21,69 | 178,76 | 13,85 |
| Voer06 | 3,14 | 6,12 | 7,91 | 0,65 | 16,35 | 6,11 | 1941,90 | 125,53 | 23,70 | 285,17 | 12,17 |
| Voer13 | 3,12 | 5,79 | 18,88 | 1,32 | 29,25 | 7,37 | 2814,90 | 108,26 | 23,11 | 218,83 | 14,30 |

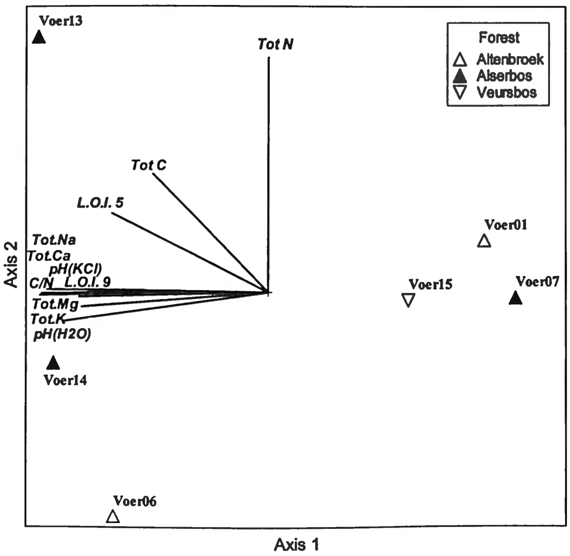


Fig. 6 — PCA diagram of all ancient forest sites based on 11 soil variables; sites represented by ▲ with overlay of the forest complex they belong to (cum% var axis1=72.42%; axis 2: cum% var=91%).

higher LOI 550 °C: 16.35% - 29.25% (cf. group B: 0.80% - 13.95%), a higher content of basic cations and higher C/N ratio: 12.17-14.30 (cf. group B: 6.93 - 10.30). The soil conditions in the valley forest stands are thus clearly different from these of the sites on the plateaus.

*b) Vegetation composition*

The first axis from the PCA diagram from Fig. 7 is strongly positively correlated with the coverage of grasses and mosses. The sites on the left of the PCA diagram have a higher coverage of leaf-litter (VOER01, VOER07 and VOER15). This is the group with low pH, low organic material content and low concentrations of basic cations (group B from Fig. 6 = forests on the plateaus). This confirms the results from the soil variables. The group of the forests on the plateaus has a more acid soil with less decomposition of litter and less possibilities for grasses and mosses to develop. In the valley we have a different soil type and we find high coverage of grasses as *Holcus mollis* and *Poa trivialis* and herbs as *Ranunculus repens* and *Ranunculus auricomus*.

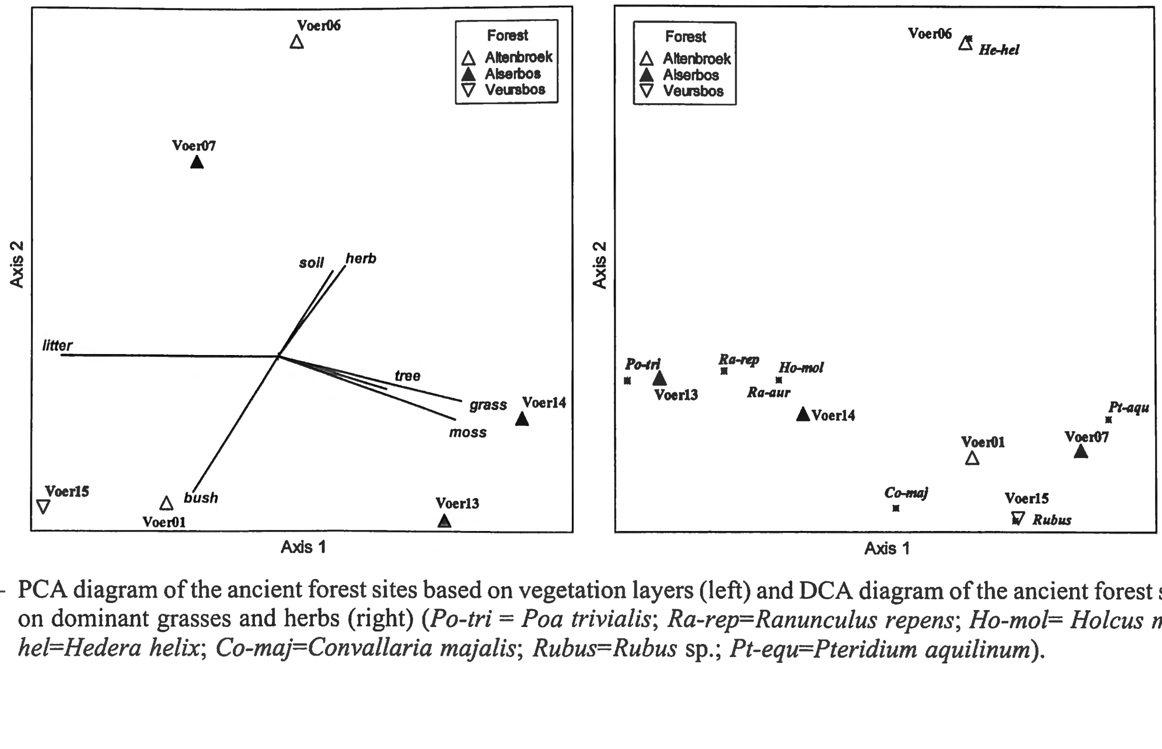


Fig. 7 — PCA diagram of the ancient forest sites based on vegetation layers (left) and DCA diagram of the ancient forest sites based on dominant grasses and herbs (right) (*Po-tri = Poa trivialis*; *Ra-rep=Ranunculus repens*; *Ho-mol= Holcus mollis*; *He-hel=Hedera helix*; *Co-maj=Convallaria majalis*; *Rubus=Rubus* sp.; *Pt-equ=Pteridium aquilinum*).

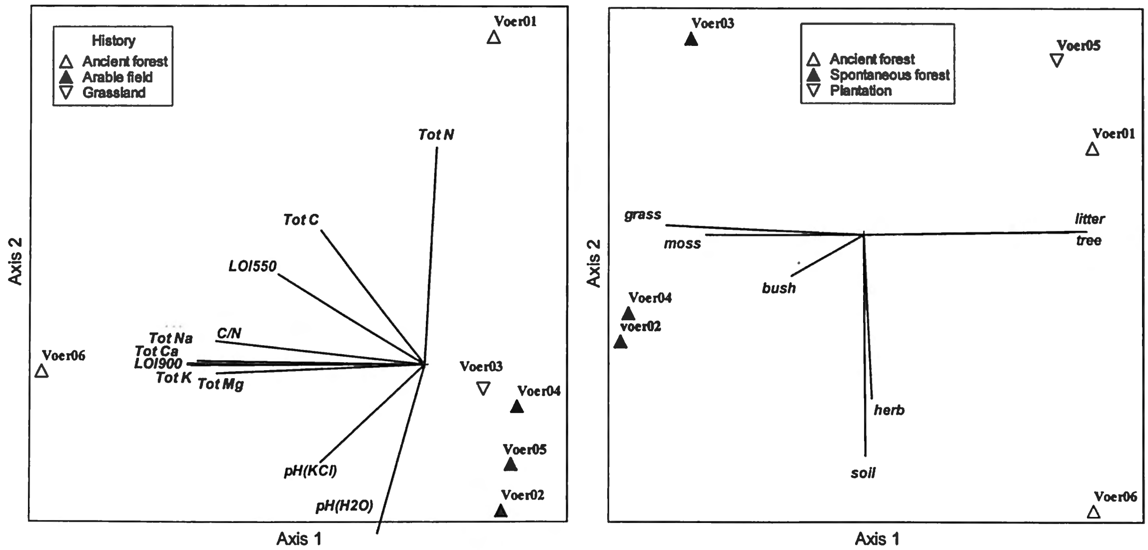


Fig. 8 — PCA diagram (axis1-2) of all forest sites in the Altenbroek based on 11 soil variables (left) and PCA diagram (axis1-2) of all forest sites in the Altenbroek based on vegetation layers (right).

– Spontaneous afforestations and plantations on former agricultural fields in the Altenbroek and the Alserbos

In this part we compare the characteristics of the ancient forests with the conditions in the new forests within each forest complex.

*a) The Altenbroek*

The PCA diagram in Figure 8 represents all forest sites in the Altenbroek based on 11 soil variables (on the left) and the vegetation layers (on the right). Ancient forests differ from all young forest stands in higher C content and higher organic matter content (LOI 550 °C). The young forests seem to have a soil type comparable with the ancient forests on the plateaus. Vegetation is a different story. The plantation already resembles the ancient forest vegetation composition, with already high tree and litter coverage and hardly any grasses, shrubs and mosses. The spontaneous afforestations have a completely different vegetation composition than the plantations.

*b) The Alserbos* (Fig. 9)

Again the first axis in the PCA diagram based on soil characteristics can be understood as a rate of decomposition or mineralization or nutrient turn-over. All new forest stands and VOER07 (reference plot near the plateau of the Alserbos) are ordinated on the left of the figure. The most important vegetation variables are coverage of grasses, trees and bare ground soil. Nevertheless the importance of a good developed grass layer is only recognizable in the plantation with *Prunus avium* on former grassland. In the two other plantations (VOER08 and VOER12) this grassland history is not detectable anymore.

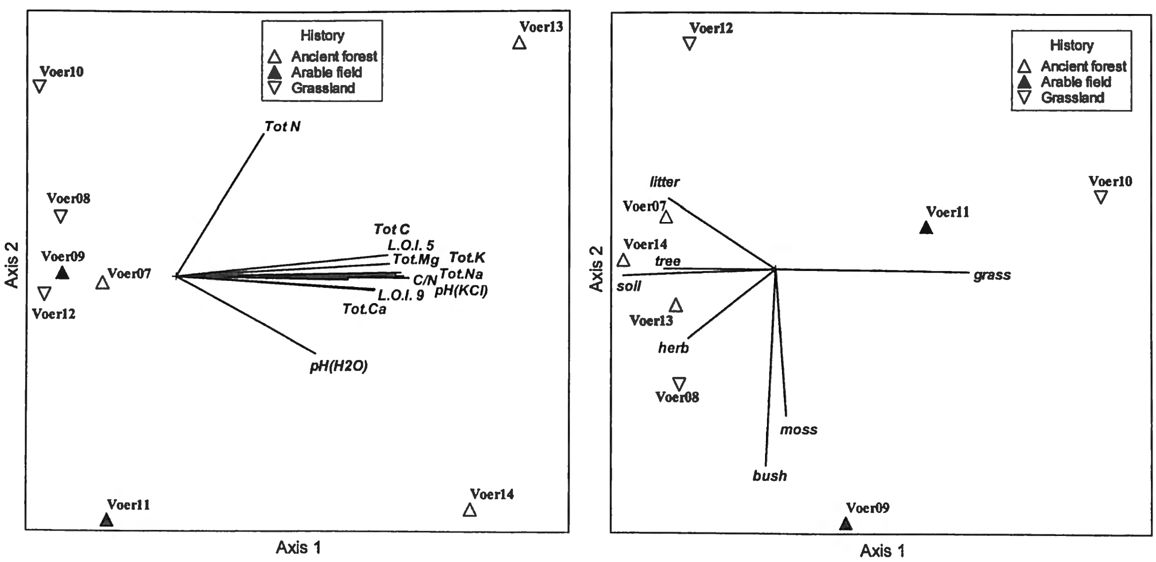


Fig. 9 — PCA diagram (axis1-2) of all forest sites in the Alserbos based on 11 soil variables (left) and PCA diagram (axis1-2) of all forest sites in the Alserbos based on vegetation layers (right).

***Forest-specific species absent: analyses and reduction of the environmental variables for entomofauna groups from all sites together***

When no forest-specific species are observed within the studied entomofauna group, we can study all 15 sites for soil dwelling fauna groups or 11 sites for non soil dwelling fauna groups together.

*a) Evaluation and reduction of vegetation and litter variables at pitfall-level*

Most soil-fauna groups are considered as potentially site-specific and sometimes very locally adapted as they react quickly to changes of environmental conditions such as microclimate and soil (BROMHAM *et al.*, 1999; DUELLI *et al.*, 1999; KOTZE & SAMWAYS, 1999). In this part, we will try to characterise microclimate and microhabitat of each sampling unit at pitfall level. A Principal Components Analysis was conducted in order to reduce 7 vegetation and litter variables of 45 sampling units (pitfalls). This detailed level of analyses can only be used if the soil dwelling fauna does not show forest-linked species or genera.

The PCA in Fig. 10 reduces 7 variables into three significant vectors, which together explain 78.88% of the total variance (Table 6). The first axis is positively correlated with high tree coverage, high leaf-litter amount and low grass cover; this reflects the vegetation composition of all ancient forest sites and the two oak-plantations (VOER05 and VOER12). Pitfalls from sites VOER08 and VOER09 are surrounded with a high coverage of mosses and herbs and are significantly correlated with the second PCA axis. The third axis is significantly correlated with a low amount of bare ground.

In general we find very little variation within each site. All three pitfalls of each site are clustered close to each other. The differences between sites are in general larger than within sites. Therefore we will conduct and use vegetation and litter characteristics for further analyses at site level as an average of the three pitfalls.

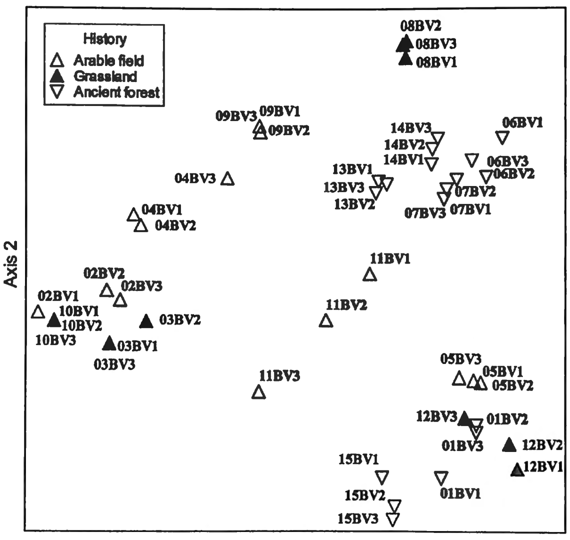


Fig. 10 — PCA diagram (axis 1 and 2) of all pitfalls based on 7 vegetation and litter variables; pitfalls represented by ▲ with overlay of their history.

Table 6 — Cumulative % of total variance of the different PCA axes and correlations of studied vegetation characteristics with the different axes; significant correlations in bold for all pitfalls (n=45).

| **Vegetation variables** | | | |
|---|---|---|---|
| | Axis 1 | Axis 2 | Axis 3 |
| Cum% var | 43.93% | 65.38% | 78.88% |
| Bare ground | 0.2826 | 0.0607 | **-0.8250** |
| Grass | **-0.5398** | -0.0078 | -0.0236 |
| Shrubs | -0.3278 | 0.0641 | -0.2010 |
| Herbs | 0.1813 | **0.6369** | -0.2309 |
| Trees | **0.5092** | 0.1521 | 0.2317 |
| Mosses | -0.0632 | **0.6805** | 0.3554 |
| Leaf lit | **0.4745** | -0.3167 | 0.2126 |

*b) Evaluation and reduction of all environmental variables at site-level* (15 sample units for soil dwelling fauna and 11 sample units for non soil arthropods)

Vegetation and litter characteristics

• 15 sites, soil dwelling fauna. At this level the first three axes in the PCA diagram (Fig. 11 left) explain 74.13% of the total variance. The first axis is positively correlated with high tree coverage, high leaf-litter amount and low grass coverage which are in general the vegetation composition of all ancient forest sites and the two oak-plantations. The second axis represents the amount of herbs in the sites and the third axis (not presented in Figure 11) is positively correlated with high mosses layer and low coverage of bare ground.

• 11 sites, non soil dwelling fauna. This PCA (right on Fig. 11) reduces all vegetation characteristics into four significant axes which together explain 89.76% of the total variance. The first axis is positively correlated with high leaf litter- and humus coverage and negatively correlated with high shrub cover and vegetation structure. Sites positively correlated with the first axis are those with a uniform low vegetation layer and with a well developed leaf-litter or humus layer. Sites with well developed grass-layer such as VOER03, VOER10 and VOER11 are positively correlated with the second axis. These sites also have rather low and uniform vegetation. The third axis is positively correlated with a poor moss layer. Finally, the fourth axis correlates with high coverage of bare ground.

Soil characteristics

• 15 sites, soil dwelling fauna. This PCA (left on Fig. 12) reduces the soil characteristics into two significant vec-

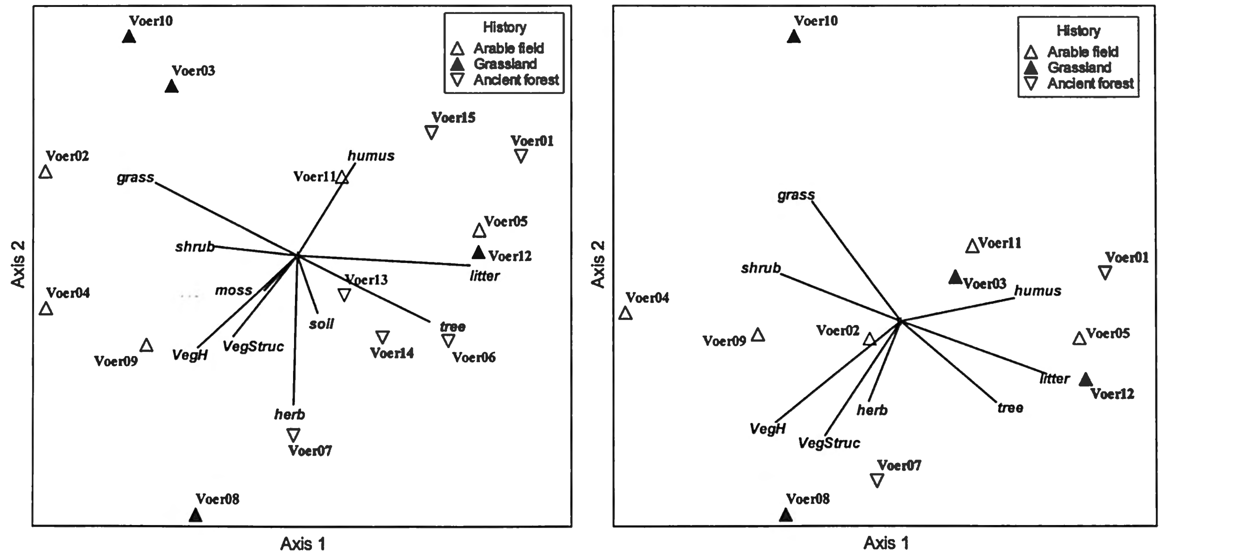


Fig. 11 — PCA biplot-diagrams (axis 1 and 2) of all sites based on 10 vegetation and litter characteristics; the sites represented by ▲ with overlay of their history; left 15 sites and right 11 sites.

tors (axis 1 and 2), together responsible for 84.68% of the variance. Negatively correlated with the first axis are Tot $Ca^{2+}$, Tot $Mg^{2+}$, Tot $Na^{+}$, Tot $K^{+}$ and LOI 900 °C. We can distinguish a group of sites with pitfalls situated in poor mineral soils which are all situated on top of the Altenbroek or Alserbos plateau and on top of the Veursbos plateau. On the other hand we observe nutrient-rich sites as VOER13 and VOER14 situated in the Alserbos valley and VOER06, located on the slope of the Altenbroek valley. All have probably been enriched with nutrients leaching out of the plateau tops. The second axis is positively correlated with soils with a high N content as found in VOER01, VOER07, VOER10, VOER13 and VOER15.

• 11 sites non soil dwelling fauna. This PCA (right on Fig. 12) reduces the soil characteristics into one significant variable (axis 1) which is responsible for 56.9% of the variance. It represents the amount of mineral soil nutrients. Sites with high concentrations of $Ca^{2+}$ and $Mg^{2+}$ and high pH (about 6.2) are positively correlated with the first axis. Those sites (VOER02-05, VOER11 and VOER12) also have a soil poor in C and N.

General results for 15 sites

From the PCA analyses of the 15 sites, five composite variables can be deduced (two soil and three vegetation variables): Soilvar15-1 = nutrient richness of the soil; Soilvar15-2 = N-concentration; VEG15-1 = tree- and leaf-litter cover; and cover of the grass-layer; VEG15-2 = herbs coverage; VEG15-3 = coverage of moss layer and amount of bare ground.

General results for 11 sites

From these PCA analyses five composite variables (one soil and four vegetation variables) can be derived (Soilvar11-1: amount of $Mg^{2+}$, $Ca^{2+}$, pH and C and N;

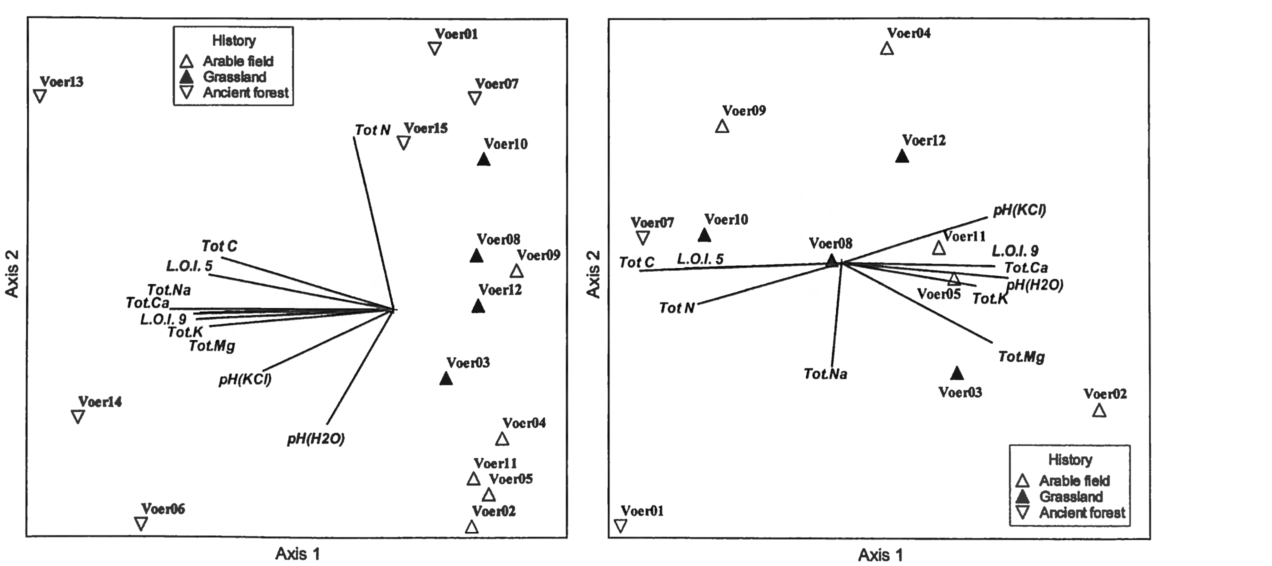


Fig. 12 — PCA biplot-diagrams (axis 1 and 2) of all sites based on 10 soil characteristics; the sites represented by ▲ with overlay of their history; left 15 sites and right 11 sites.

Table 7 — Cumulative % of total variance of the different PCA axes and correlations of studied vegetation characteristics with the different vectors; significant correlations (see Table 4) in bold for 15 sites.

| Vegetation VAR15 | | | |
|---|---|---|---|
| | **Axis 1** | **Axis 2** | **Axis 3** |
| Cum% var | 34.03% | 61.70% | 74.13% |
| Bare ground | 0.1594 | -0.2932 | **-0.5975** |
| Grass | **-0.4194** | 0.3263 | -0.1430 |
| Shrub | -0.3232 | 0.1188 | 0.0740 |
| Herbs | -0.0647 | **-0.4753** | -0.0759 |
| Trees | **0.4042** | -0.3151 | 0.1803 |
| Mosses | -0.2017 | -0.2298 | **0.4783** |
| Leaf-litter | **0.4610** | -0.1230 | 0.1932 |
| Humus | 0.2676 | 0.3698 | 0.4689 |
| VegH | -0.3504 | -0.3745 | 0.2275 |
| VegStruc | -0.2813 | -0.3510 | 0.2026 |

Table 8 — Cumulative % of total variance of the different PCA axes and correlations of studied vegetation characteristics with the different vectors; significant correlations (see Table 4) in bold for 11 sites.

| Vegetation VAR11 | | | | |
|---|---|---|---|---|
| | **Axis 1** | **Axis 2** | **Axis 3** | **Axis 4** |
| Cum% var | 35.63% | 63.27% | 79.07% | 89.75% |
| Bare ground | -0.1573 | -0.1996 | 0.3284 | **-0.7431** |
| Grass | -0.3218 | **0.4228** | -0.1303 | -0.1984 |
| Shrub | **-0.3743** | 0.2682 | -0.0756 | -0.3461 |
| Herbs | -0.1935 | -0.3510 | -0.4614 | 0.0818 |
| Trees | 0.3325 | -0.3518 | -0.3105 | -0.1993 |
| Mosses | -0.2154 | -0.1256 | **-0.6348** | -0.1296 |
| Leaf-litter | **0.4117** | -0.2842 | 0.1288 | -0.2155 |
| Humus | **0.3630** | 0.1874 | -0.2860 | -0.4149 |
| VegH | **-0.3835** | **-0.3940** | 0.0522 | 0.0734 |
| VegStruc | **-0.2981** | **-0.4191** | 0.2367 | -0.0384 |

VEG11-1: uniform vegetation layer and the coverage of leaf-litter and humus -layer; VEG11-2: coverage of grass-layer; VEG11-3: coverage of moss-layer and VEG11-4: coverage of bare ground. They can help to explain environmental variance at site-level for 11 sites where non soil dwelling arthropods were studied.

## Discussion and conclusions

### *Forest-specific fauna present*

We can conclude that to evaluate the effects of afforestation on former agricultural fields in the here considered Voeren-region, the width of the environmental analysis to apply will depend on a preliminary study of the considered arthropod group. If we find a lot of forest-specific species we have to analyse both forest complexes separately.

When we consider the two forest complexes separately however similar conclusions for the Altenbroek and the Alserbos can be made. Ancient forests differ from all young forest stands in higher C, higher Loss On Ignition 550 °C (organic material) and higher concentration of cations. The rate of decomposition and mineralization or nutrient turn-over seems very important and of importance for present vegetation structure and composition. More nutrients and a less acid environment favor biode-

Table 9 — Cumulative % of total variance of the different PCA axes and correlations of studied soil characteristics; significant correlations (see Table 4) in bold for 15 sites.

| Soil Variables15 | | |
|---|---|---|
| | **Axis 1** | **Axis 2** |
| Cum% var | 64,19% | 84.68% |
| pH(KCl) | -0.2779 | -0.3350 |
| pH($H_2O$) | -0.1983 | -0.4591 |
| Tot C | -0.3193 | 0.3056 |
| Tot N | -0.1535 | **0.5608** |
| L.O.I. 500 °C | -0.3311 | 0.2490 |
| L.O.I. 900 °C | **-0.3440** | -0.0882 |
| Tot.Ca | **-0.3386** | -0.0783 |
| Tot.Mg | **-0.3302** | -0.1762 |
| Tot.Na | **-0.3641** | -0.0276 |
| Tot.K | **-0.3417** | -0.1375 |

Table 10 — Cumulative % of total variance of the first PCA axis and correlations of studied soil characteristics with the different vectors; significant correlations (see Table 4) in bold for 11 sites.

| **SOILvar** | **Axis 1** |
|---|---|
| Cum% var | 56,90% |
| pH(KCl) | 0.3267 |
| pH($H_2O$) | **0.3492** |
| Tot. C | **-0.3853** |
| Tot. N | **-0.3249** |
| L.O.I. 500 °C | -0.3393 |
| L.O.I. 900 °C | 0.2736 |
| Tot. Ca | **0.3346** |
| Tot. Mg | **0.3316** |
| Tot. Na | -0.0849 |
| Tot. K | 0.3134 |

gradation of the forest floor. However in both forest complexes the plantations have developed already similar vegetation layers as the ancient forest stands.

***No forest complex specific-fauna present***

For some studied entomofauna groups we will not have forest-specific species, i.e. the fauna of the ancient forest sites of the Altenbroek resembles the fauna from the ancient forests in the Alserbos. In this case we can study all sites together. The level to analyse in such case depends on the considered group and used sampling method (pitfall or other traps) and study area (15 or 11 sites). A more detailed pattern of variation could be distinguished at pitfall (and microhabitat-) level. Then, the number of sampling units is larger which would allow us to detect smaller differences. Also, the general environmental differences between the sampling units are more pronounced.

Importance of soil conditions

At both levels (15 sites and 11 sites), the same trend and a similar influence of soil composition, was found. The amount of nutrients and mineral richness is the most important soil variable, which divides all sampling units in two groups. The reasons therefore can be found in a historical and geographical context. Through ages, all minerals as $Ca^{2+}$, $Na^{+}$, $Mg^{2+}$ en $K^{+}$ have been leached from the tops of the hills of both forest complexes towards the valleys and along the slopes. This resulted in high concentrations of minerals nowadays found in the valleys or downwards the slopes of plateaus. A characteristic calcareous flora (*Clematis vitalba*, different Orchids, *Paris quadrifolia*,....) is also situated there (JACQUEMYN *et al.*, 2003). Perhaps the presence of some species or entomofauna genera will be more influenced by this soil character than by the here investigated historical land use characteristics. Nevertheless, a historical reason can also be important in those cases. In ancient times, forests along steeper slopes and in valleys were more often left aside and only few of them were transformed to agricultural sites because farmers did not need these 'non-practical' forest-stands. The hill tops and plateaus were much more appropriate for agricultural activities i.e. they are flat and can easily be farmed. At most locations this farming situation was only temporary. Most of those agricultural plots (for example those in the Alserbos) were cultivated for a short period only because they were poor in nutrients and less fertile and contained too many stones. So ancient and $Ca^{2+}$-rich forests will contain a typical old forest and/or calcidophilous arthropod fauna. Another important soil characteristic that could be of importance for particular entomofauna elements in the studied sites, is N-concentration. We found N-rich soils in some reference sites (VOER01, VOER07, VOER13 and VOER15) and in the former grassland site, planted with *Prunus avium*. This is somewhat surprising because one might have expected high N-concentrations on the former arable land sites due to former fertilisation activities. Probably also some of the N-stock has been leached out towards the lowest ancient forest sites.

The main conclusion here is that in some situations and for some species or arthropod genera, soil composition (especially $Ca^{2+}$-rich sites) could be the most important factor for their occurrence in particular sites, instead of the influences we want to detect caused by forest succession and land use history. In general little or no influence of ancient agricultural practices (such as high N-concentrations) could be detected in the former agricultural soils, probably because all former grasslands and arable fields were only farmed during short periods and enrichment by fertilisers has been leached out since.

Importance of vegetation structure and forest succession on former agricultural sites

At both levels (pitfall and site) the same patterns can be observed. The most important vegetation characteristics is forest structure and variables related to this, i.e. cover of leaf-litter and of trees. At pitfall-level also coverage of grasses can be important.

Changes in vegetation and landscape structure are of major importance for the occurrence and abundance of insects. During succession from former agricultural land towards forests, vegetation structure changes continuously and also the possibilities for insects alter during this process. The analyses suggest that the current state of vegetation characteristics are a reflection of the progress of forest succession at each site. The longer a site is abandoned and forest succession is ongoing, the more the vegetation structure and composition resembles that of ancient forest sites. This process is additionally favoured if former agricultural sites are planted with autochthonous trees as found on site-level when only sites on the plateaus of Altenbroek and Alserbos are considered.

Other environmental variables

Environmental variables as distance to forest, distance to open field, the amount (mg/kg soil) and type of stones, amount of dead wood,% sunlight reaching the soil and grazing intensity were listed as categorical variables. We will use these in a descriptive way, when composing PCA and or other multivariate overlays as we have already done here a few times. They can help to understand observed structure in our analyses, unexplained by the other variables. In addition, we had the opportunity to evaluate the difference between low density grazing (8 Galloways on 42 ha) and intensive summer grazing on the arthropod fauna in this ongoing forest succession. We could not detect any clear difference between both. Probably, the time elapsed since the start of the experiment is too short to create detectable differences.

***General conclusions and discussion***

In this paper we tried to classify our sample units (pitfall and sites) according to soil-, vegetation- and some other characteristics. We found some general trends, which are, as expected, similar for all considered possibilities (levels) of analysis. The question now remains whether these variables will relate to and explain the occurrence of different soil and non-soil dwelling fauna groups. If we find trends in multivariate and univariate analyses (ordinations and classifications) of arthropod communities that are similar to those found in the analyses of the soil and vegetation variables, we can assume that we have found the most important environmental variables for the group under consideration. If no similar trends are revealed, we will have to check if the classification of the sampling units based on species composition are perhaps caused by history or history-linked variables. Although most vegetation and also soil characteristics are a reflection of site-history, it could also not be the case. Perhaps only for part of the arthropod-groups studied important environmental factors will be found. Because of the rather special zoogeographical nature of the Voeren region, it is also possible that the results found here for a particular group can not be extrapolated to other regions of Flanders.

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