Multiparameter analysis of vertical vegetation structure based on digital image processing

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Submitted: Sept 6, 2002 · Accepted: Nov 15, 2002

Summary

Changes of vertical arrangements in plant communities cause changes in processes and habitat parameters such as microclimate, nutrient cycles, arthropod behaviour and others. Therefore the description and analysis of structural dynamics is the basis for investigations at the level of processes. With VESTA (Vertical vegetation Structure Analysis), an improved photographic method of analysing vertical vegetation structure was designed to study various spatial parameters, especially in pioneer and grassland ecosystems. Following standardised data sampling in the field based on digital photography, the spatiotemporal characteristics of the vertical vegetation structure can be extracted by a newly elaborated software (SideLook). The new method is introduced, and parameters of analysis such as “denseness” and “roughness” are defined. Evaluation of the method gives these main results:

– multiple structural characteristics of vertical vegetation structure can be obtained on the basis of digital images,
– the method is quick and easy to apply in nearly all weather situations,
– the data output is robust against differences between persons using the method,
– the effects of optical distortions are slight, and height and other parameters are robust in a comparison to field data,
– a good correlation with above-ground phytomass coverage was found, and
– the data output can easily be used for subsequent data analysis, e.g. by ordination techniques.

In order to demonstrate the possibilities of VESTA with reference to some examples, the following studies are introduced:

– Structural data for six plant communities were discriminated by a PCA, showing the gradients of succession on sandy soils.
– Spatio-temporal changes such as phenological rhythmicity are depicted.
– The grazing impact is characterized as an example of disturbance processes: Here the upgrowth continues on the ungrazed plots whereas height parameters decrease and the spatial heterogeneity increases under sheep grazing.

Key words: VESTA method with SideLook software, image analysis, vegetation denseness, spatiotemporal changes, sheep grazing, sand ecosystems.

Abbreviations: bpd: black pixel denseness, ssh: sward surface height (average vegetation height according to Edwards et al. 1995), VESTA: Vertical vegetation Structure Analysis, wpd: white pixel denseness

1. Introduction

Vegetation structure plays an important role in plant-plant interactions and plant-soil interactions such as changes within the reproductive cycle (Sundermeier 1999), weed repression (Seavers & Wright 1999) and seedling establishment (Fothergill et al. 1997), as well as in relationships between plants and abiotic parameters (temperature: e.g. Barkman & Stoutjesdijk 1987; Wang & Horiguchi 1998; wind, drought, snow, humidity, light and incoming/outgoing radiation: Barkman 1979; deposition of air pollutants: Heil 1988). The
vegetation structure is also an important habitat factor for animal communities:

- tufts offer protection to beetles such as Carabidae and Staphilinidae: Meissner (1998), or other arthropods: Bossebroek (1977),
- dense vegetation structures hinder surface-dwelling arthropods in locomotion: Heydemann (1957); Meissner (1998); Richards & Waloff (1954),
- the vertical vegetation structure of grassland and special behavioural strategies of animals, e.g. the escape behaviour of some grasshopper species, are correlated: Huber (1952),
- the horizontal vegetation structure on one hand influences the grazing preferences of livestock or herbivorous mammals such as ungulates, and on the other hand is processed by these animals: Adler et al. (2001); Edwards et al. (1995); Ellenboek & Wergen (1986); McNaughton (1997); Sala (1987).

This study aims to propose a reproducible method for quantifying the structural components of vertical vegetation structure. The background in which we evaluate this method is a grazing experiment in sand ecosystems (“Inland sand ecosystems: dynamics and restitution”) from 1999 until the end of 2003, funded by BMBF Germany (01LN0003). In the course of this project, effects from sheep grazing on endangered sand vegetation are studied (Schwabe et al. 2002a). Besides the study of horizontal micropattern with a computer-assisted frequency analysis at a microscale of 5 x 5 cm (POSITIO-METER-method according to Nobis 2000), the vertical vegetation structure is investigated on the basis of a standardised and optimised method which was designed in a preliminary version by Zehm (1996). Structural differences will be represented in detail and correlated with data sets regarding, for instance, soil temperature, habitat preferences of arthropods such as Ensifera/Caelifera, horizontal pattern, spatio-temporal shifts between different years and various plant communities.

Among the main questions to be answered are:

1. Which parameter – or which combination of parameters – of vertical vegetation structure is important in order to characterise whole stands, especially of grassland vegetation?
2. In which way is it possible to define stands of vegetation and features such as their temporal rhythmicity or disturbance processes on the basis of vertical vegetation structure data?

And supplementary, is it possible to correlate structural characteristics with microclimatic or biotic factors, and therefore to analyse structural qualities/quantities as indicators for abiotic or biotic factors? First we focus on points 1. and 2., but additional analysis will be possible in the course of our ongoing project.

2. Basic definitions: vegetation structure

According to Schaefer (1992) the term “structure” means first a set of connected elements of a system and second the structuring of a system with regard to spatial, temporal and functional aspects. In the following we focus on the spatial and spatio-temporal structuring of vegetation stands. According to Barkman (1979), “vegetation structure” is defined as the horizontal, vertical and temporal arrangement of vegetation (structure in the strict sense) but excludes the composition of the vegetation in terms of species, life forms, leaf morphology and so on. The latter has been defined in accordance with soil science as “texture” (see, e.g., Barkman 1979; Dierschke 1994; Kratochwil & Schwabe 2001). Structure and texture can be summarised as “structure in a wider sense”. “Temporal” means phenological/seasonal aspects and aspects of disturbance such as mowing or grazing, but not of long-term successional processes. With the exception of the “species density” (see Section 8.2.2), in the following we are concerned with structure in the strict sense.

We distinguish for the vegetation:

1. The investigation of the horizontal projection of vegetation, which means the examination of elements in plan view: structural components are, e.g., patches of vegetation and their horizontal pattern.
2. The investigation of the vertical projection of vegetation, which means the examination of elements in sideview. Structural components considered here range in size from strata such as bryophyta/lichen layers up to shrub/tree layers. Side-view analyses can be subdivided into
   a) the projection of information onto the y-axis
   b) the projection onto the x-axis and
   c) whole-picture information (e.g., the fractal dimension) – see Section 5.

To a limited extent, information about horizontal structure (e.g. the occurrence of lightgaps, see Section 5.2) can also be obtained.

Concerning vegetation analysis, the term “spatial structure” (= horizontal and vertical arrangement of vegetation) is used for approaches 1 and 2. This definition corresponds to that given by Schaefer (1992) and Barkman (1979). The term “pattern” is used by many authors for aspects such as the particular configuration of horizontal, vertical or temporal arrangements of vegetation, while others restrict it to the horizontal structure. We use it in accordance with Barkman (1979) in a restricted way, i.e. only for horizontal structure.

The term “gap” is mostly used for patches without vegetation or spotted patches lacking, e.g., the tree layer after windthrow, and therefore it is an element of horizontal structure description. To characterise the space
between vegetation elements in sideview the term “hole” (row-hole and column-hole) is introduced here. Additional parameters to describe components of vertical vegetation structure are:

- Vegetation denseness (according to Barkman 1988): amount of vegetation structures (biomass or cover)/ spatial unit; the parameter can be interpreted e.g. as the amount of phytomass of a stand or the “spatial resistance” for arthropods or other small animals (as e.g. small mammals).
- Vegetation density (according to Greig-Smith 1983) describes the number of plant individuals or plant shoots/spatial unit.
- Vegetation roughness describes the space available for interactions between plant surfaces and the boundary layer of air (according to Smith et al. 1995) expressed as the variance of measurements of the average canopy height or according to Heil (1988) as the sum of the distances between the average vegetation height and the measurement points of a grassland canopy (roughness length). Following Smith et al. (1995), we define roughness as standard deviation of the average vegetation height.

3. Established methods for studying vegetation structures

Many different methods with which to investigate vegetation structure have been described during recent years. These are methods using measurements, e.g., by Barkman (1979); Catchpole & Wheeler (1992); Dietz & Steinlein (1996) and Sundermeier (1997, 1999).

We focus on methods that are applicable to the study of vertical vegetation structure, especially in grasslands. A considerable number of approaches exist for forest stands (overview of methods see Bongers 2001; Walter 1982).

- Physiognomic characterisations of defined plant communities complemented with drawings of the stand structures. These have been used, e.g., for the description of Norwegian forest communities (Kielland-Lund 1981) or the characterisation of vegetation stands with the help of physiognomic parameters such as leaf forms (Styner & Hegg 1984). An analysis based on tree profiles by Walter (1982) leads to a classification of tree species into different architectural types.
- Approaches using categorised or measured parameters as illustrated by Barkman (1979): e.g., correlations between plant architectural types (erect or horizontally arranged) and remotely sensed temperatures of the stands (Wang & Horiguchi 1998). Employing parameters like leaf size, crown diameter, plant height and others, Pérez-Latorre et al. (2001) compared geographically separated Quercus suber stands. Other examples are the analysis of changes of morphological traits and plant forms under grazing impact (Díaz et al. 1992) or the assay of correlations among harvested phytomass per vegetation layer, leaf area index (LAI) and soil parameters for four vegetation types by Werger (1983).
- Estimation techniques such as plan-view estimation of vegetation density for height intervals according to van der Maarel (1970), small-scale denseness estimation supported by a regular grid within a “structure measuring tube” following Sundermeier (1999), counting vegetation parts that cross a virtual level by Barkman’s method (Barkman 1988) or, adapted from tree-crown research, the planar intercept method of Brown (1971), where the count and the volume of plants crossing a virtual level are recorded. The estimation of cover values for grid lines of a vertical profile in combination with plant frequency was used by Curtis & Bignal (1985) to classify peatland vegetation. Estimation of overall denseness for defined strata results in simple stratification diagrams, e.g., for forest communities (Dierschke 1994).
- Methods based on frequency counting of elements in regular grids. The often used point quadrat method devised by Goodall (1952) is based on the counting of contacts of plant elements with vertically inserted wires. Mühlberg’s (1993) vegetation hurdle uses horizontal wires as a basis for counting contacts of plant elements at various height levels to analyse vegetation density. With a multicube stratiometer (Witte & Herrmann 1995), fixed within a vegetation stand for a vegetation period, the frequencies of plant elements are counted within a three-dimensional grid for species-based research on, e.g., interspecific competition.
- Height measurements. The simplest method is the direct measurement of maximum or average height. Other methods are height analysis by means of a disk pasture meter (= plate meter), recording the ssh with a disk dropped onto the vegetation (Bransbury & Tainton 1977; Holmes 1974), or using a “sward stick” with which the height of a sheet of paper lowered to the highest part of the green vegetation is measured (Barthram 1986). For further information to this topic see also the detailed comparison of these methods by Stewart et al. (2001).
- Sensor methods measure the light passing through different layers (method reviewed by Perry et al. 1988). The absorption of pulsed infrared light was recorded with the vegetation stratimeter (Oppermann 1989) in order to compare vegetation stands and to analyse phenological rhythms. The laser densitometer of Gerstberger & Ziegler (1993) records the light reflected by the plant surfaces.
- Photographic systems. With photos taken against a translucent background (Roehrensen et al. 1988) or a white background with subsequent phytomass estimation (Born 1990; Brinkmann 1991) vegetation stands are analysed.
- Measurement of element orientation. One example is the “Pocimeter” introduced by Takenaka et al. (1998) as a means of recording the three-dimensional orientation of leaves with little effort. Two alternative methods for orientation analysis, the “orthogonal projection” and the “Fredholm Integral Equation”, were compared for an Agropyron smithii stand by Smith et al. (1977).
- Some point methods, e.g., the “point wheel method” of Griffin (1989) with manual recording of parameters in a
point series, have been proposed. Further information is given by Everson & Clarke (1987) in a method comparison.

So far no method for the analysis of vertical vegetation structure has become established for widespread use. From comparative publications (see Barkman 1979; Sundermeier 1997, 1999; Dietz & Steinlein 1996) it appears that most methods for vegetation structure analysis are time consuming, cause severe vegetation disturbances, require expensive equipment or yield information about only one aspect of vegetation structure.

The photographic methods seem to be well reproducible and quite effective, but problems are known to be associated with the separation between vegetation and background (see Sundermeier 1999), standardisation of the photography and handling large data sets.

The method described here is an improved photographic method based on Curtis & Bignal (1985) and Roebertsen et al. (1988), combined with digital picture processing. Therefore a huge data set comprising different structural components in each stand can be gathered in a suitable time (see Section 5).

4. Methods: recording data in the field

4.1 General remarks and sampling design

The VESTA method (VErtical vegetation STRucture Analysis) refers to the vertical vegetation structure photographed in side view against an artificial background, the length and height of which provide a x- and y-axes of a coordinate system. The distribution of plot areas may follow a random or systematic design or may be combined with subjectively chosen plots of definable vegetation types, depending on the question.

In our case studies the sampling design was systematic-random stratified according to defined vegetation complexes (Schwabe et al. 2002a; Zehm et al. 2002, see also Sections 8.1 and 8.2). The number of plots for vertical vegetation structure analysis in central European grasslands should be at least 3 for plant communities dominated by small plant individuals (e.g. Corynephorion) and 4–6 in species-rich areas (e.g. Mesobrometum) or stands dominated by tall plants like Artemisietea communities. The standard picture plot area of 1 m × 30 cm (see Section 4.2) should be maintained in order to enable comparison of the results of assays by different authors, unless special questions are to be addressed.

Exceptionally tall plants within the stand (e.g., single Verbascum shoots or scrub individuals) should be treated separately and not be included in the standard data gathering. As in the harvesting method for phytomass evaluation (Janetschek 1982), the amount of these elements should be estimated for the area of interest in an accessory collection process and added to the results of the standard method.

4.2 Digital photography

The first step in structure analysis is to obtain an image of the vegetation stand. The preparations for digital photography are the following:

1. Selecting a 100 cm × 30 cm test area within the vegetation stand to be investigated (adequate for open stands).
2. Covering the vegetation in front of the plot stripe with a sheet of plastic tarpaulin and pressing it down to the ground (Fig. 1).
3. Fixing the artificial background in position behind the plot stripe; it consists of an opaque cloth, optionally black on one side and white side on the other for alternative usage. The cloth is about 1 m wide, a minimum of 80 cm high and has to be fixed without any fold down to the ground level. On one side a picture number and a cm standard with alternating black and white ribbons of 10 cm distance across the tape is attached (Fig. 1).
4. Fixing the camera in the standard position, 140 cm away from the cloth and 25 cm above the ground.

Although the plot area can be left undisturbed, about 2 m² are necessary for taking a single image because the vegetation is pressed flat for some distance in front of the analysed layer. When the pictures are taken along a line, the disturbed area can be reduced to 0.5 m² per picture because the flattened regions in front of the test areas overlap one another.

Two pictures (one should be overexposed on purpose) were always taken of each sample area with a digital camera, to ensure that one of them would show optimal discrimination between vegetation structure and black background. A standard digital camera (used here: Olympus Camedia C1000-L and C2500-L) is sufficient.

A picture resolution of 1024 × 768 pixels should be the minimum for data collection. With this resolving power and the sampling design in this study, the pixel size is about 1 mm².

4.3 Recording of additional field data

As a reference for the exact maximal vegetation height the tallest shoot was measured in the investigated plot. To determine species quality, diversity and the importance of single species for the spatial structure of the stand, a species-based estimation of vertical cover per-
percentages has to be done. Compared to the horizontal cover scale of Brau-Blanquet (1964) a percentage scale was used such that the total of all cover values was equal to 100% cover. A classical Braun-Blanquet relevé (Dierschke 1994) exceeding the minimal area should complete the data collection for community classification.

Textural data, such as the proportion of the different plant species within the stand, life form, leaf structure, branching degree etc. can be integrated into this approach, for instance by means of multivariate analysis.

4.4 Working with the program “SIDELOOK”

4.4.1 Picture import and data processing

After the standardised digital photos have been collected in the field, the pictures are imported in BMP or JPEG format to the software tool SIDELOOK (written by M. Nobis). We recommend high-quality JPEG picture compression as standard picture format. After setting a scale by choosing two points a known distance apart, delimiting the area of interest within the picture, transforming the picture into a two-bit black (vegetation) and white (background) image, SIDELOOK calculates the spatial parameters that describe the structural arrangement (see Section 5).

4.4.2 Data storage

The adjustments made during the picture processing are saved in a small script file (size less than 1 kbyte), whereas the structure values will be logged in an extra file. With help of the script file an additional saving of the transformed picture is unnecessary and supplementary calculations can be made self-acting for a set of pictures (batch mode).

5. Methods: Structure parameters analysed by SIDELOOK

5.1 General remarks

For the analysis the picture is divided into vertical columns (column parameters: Fig. 2,1) and into horizontal rows (row parameters: Fig. 2,2). Whole-picture
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<table>
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<tr>
<th>x, y, w [unit]</th>
<th>Sketch</th>
<th>x, y, w [unit]</th>
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<tr>
<td>height (cm)</td>
<td>x</td>
<td>density (%)</td>
<td>y</td>
<td>column denseness</td>
<td>x [cm]</td>
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<tr>
<td>width (cm)</td>
<td>y</td>
<td>column denseness variation</td>
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<td>Vegetation filling Zeilen</td>
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<td></td>
<td>w [m²/mg]</td>
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<td>Vegetation filling Spalten</td>
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<td></td>
<td>vegetation denseness</td>
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**English**
- x-analysis = column analysis
- y-analysis = row analysis
- y-analysis = Zeilenanalyse
- x-Analysen = Spaltanalyse
- y-Analysen = Zeilenanalyse
- Total area of black pixels in relation to the picture width.

**German**
- x-Analysis = Spaltanalyse
- y-Analyse = Zeilenanalyse
- Total area of black pixels in relation to the picture width.

**Description**
- Analysis of parameters by cumulation of data to the x-axis.
- Analysis of parameters by cumulation of data to the y-axis.
- Black pixel area of a row height interval in relation to the total row area.
- Black pixel area of a column interval in relation to the total column width.
- Variation of column denseness calculated as standard deviation.

**White Pixel Denseness (wpd) = Lückenanteil**

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Description</th>
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<tbody>
<tr>
<td>x, y, w [unit]</td>
<td>Sketch</td>
</tr>
<tr>
<td>y (cm)</td>
<td>Average row-hole size</td>
</tr>
<tr>
<td>German</td>
<td>Lückennmittel</td>
</tr>
<tr>
<td>Description</td>
<td>Average of hole sizes for a given height interval.</td>
</tr>
</tbody>
</table>

**English**
- Average row-hole size
- Maximum hole size
- Row-hole count

**German**
- Lückennmittel
- Maximale Lückengröße
- Lückenzahl

**Description**
- Average of hole sizes for a given height interval.
- Biggest hole for a given height interval.
- Number of holes for given height intervals.

**White Pixel Denseness (wpd) = Lückenanteil**

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Description</th>
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<tbody>
<tr>
<td>x, y, w [unit]</td>
<td>Sketch</td>
</tr>
<tr>
<td>y (cm)</td>
<td>Hole-maximum height</td>
</tr>
<tr>
<td>German</td>
<td>Schichthöhe</td>
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<tr>
<td>Description</td>
<td>Height of stratum with largest hole count.</td>
</tr>
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</table>

Fig. 2.
parameters are calculated for the entire selected frame. These calculations will be done for freely chosen height or width interval sizes between 1 cm and the maximum height or width of the picture.

The SideLook results are normally displayed as a list of the results obtained for each interval over the chosen analysis frame size for all the selected parameters. The parameters specified here can easily be calculated from these results by computing, e.g., the average or the standard deviation of the raw data.

5.2 Black pixel denseness (= bpd)

Black pixels within the selected frame area are interpreted as vegetation structures. The bpd is a count of black pixels in the analysed picture area.

- vegetation denseness (Fig. 2,3): Overall relative vegetation cover represented by the picture, calculated as the total area of black pixels in relation to the picture width. It can be interpreted as the amount of phytomass within the picture.
- **row denseness** (Fig. 2.4): Cumulation of all black pixels to the y-axis, related to the total number of pixels within all height intervals. Commonly displayed as partitioning curve of vegetation cover/row (e.g. FLIEVOET & WERGER 1984; KOBLET 1979; KRETCHWIL 1989) showing the strata partitioning of vegetation denseness.

- **column denseness** (Fig. 2.5): Cumulation of black pixels to the x-axis, displayed as relative vegetation cover represented by a given column. It is calculated as the total area of black pixels in relation to the column width. It can be interpreted as amount of vegetation cover within a selected width interval and therefore as a description of the horizontal allocation of vegetation denseness.

- **column denseness variation** (Fig. 2.6): Variation of column denseness (Fig. 2.5), which can be interpreted as a measure of the degree of patterning of vegetation cover (= fine-grained heterogeneity).

5.3 **White pixel denseness (= wpd)**

The white pixel denseness describes the holes between the vegetation parts and/or between vegetation and the frame margins. Mainly row analyses are performed because of the high vulnerability of column analysis to wind. Except for the light gaps (Fig. 2.12) all wpd are measures of the openness and the spatial resistance (impediment to movement of, e.g., arthropods) of a vegetation stand.

- **average row-hole size** (Fig. 2.7): Average of all hole sizes within the analysis interval.

- **maximum hole size** (Fig. 2.8): Size of the biggest hole within the analysed interval.

- **row-hole count** (Fig. 2.9): Number of holes within the row interval.

- **hole-maximum height** (Fig. 2.10): Displays the height in cm with the absolute maximum count of holes. Next to the ground the coverage by vegetation elements is nearly complete; only a few small holes are present. Near the canopy the few irregularly distributed elements are separated by huge holes. Therefore a maximum hole number will be found at an intermediate height level. The row-hole data have to be checked for other local maxima that would indicate a subordinate strata change or result from data noise. The risk of maxima caused by data noise can be diminished by increasing analysis interval sizes or using a running average.

- **column-hole count** (Fig. 2.11): Sum of holes within a column, affecting e.g. the light transmission to the ground surface.

- **light gap** (Fig. 2.12): Area with a column denseness below a specified level (e.g., 5 cm height) such that a transmission of solar irradiance down to the ground is possible. The level can be adapted, e.g. according to the objective of the project or to a measured relative irradiance.

5.4 **Height parameters**

- **maximum height** (Fig. 2.13): Peak of the highest vegetation element within the image.

- **altitudinal profile** (Fig. 2.14): Series of peaks of the highest vegetation elements within the selected intervals.

- **sward surface height (= ssh)** (Fig. 2.15): Calculated as average of the maximum height in all 1-cm intervals (nmin > 80) within the image (altitudinal profile), following EDWARDS et al. (1995).

- **roughness** (Fig. 2.16): The variation (standard deviation) of the altitudinal profile describes the roughness (= height heterogeneity) of the canopy.

- **100%, 95%, 90%, … height** (Fig. 2.17): Height below which a percentage of vegetation cover (based on bpd) is located. E.g., the 90% height is a height measure omitting the extremely high elements such as tall grass inflorescences.

5.5 **Other parameters**

- **topline length** (Fig. 2.18): Calculates the sum of the distances (City-Block-Distance) between the highest black pixels in all one-pixel-wide columns of the image. A measure of the roughness of the stand. Affected by the picture resolution, the arrangement of vegetation elements regarding wind impact and contamination of black pixels in the upper part of the image (see Section 6.2).

- **freely chosen point series** (Fig. 2.20): Enables special-interest analysis in addition to the programmed possibilities: e.g., an examination of the height or density of inflorescences within the picture.

- **fractal dimension** (Df): (Fig. 2.19): The fractal dimension (MANDELBROT 1983) is a means of comparing the proportion of lines to surfaces in pictures of equal dimensions. The Df is calculated with the box-counting algorithm (e.g. HÜTT 2001). For example, selective grazing on huge-leaved herbs as opposed to grasses with small leaves will decrease the fractal dimension. SMITH et al. (1995) uses Df to analyse the roughness of plant species canopies in relation to wind impact without regard to species size.

- **species denseness** (Fig. 2.21): Additional estimated field data on the relative percentage cover of a species in relation to the overall vertical vegetation cover.
6. Results: Validation of the method

6.1 Relevance of optical distortions

Every projection of an image of a three-dimensional object onto a plane (including the photographing process) involves certain distortions, which will never be avoidable. Before a photo can be analysed it has to be reconstructed into the geometrically correct picture (orthophoto). In order to assess the importance of distortions, a trial run with 11 pictures of different vegetation units (pioneer vegetation: Corynephorion, and ruderalised grassland: stand dominated by *Festuca rubra*) was performed. The images were rectified using an affine transformation to orthophotos with the software tool Raster-Manager for Bentley Microstation with reference to the known rectangular sizes of the background area. For structure elements that are not in the same plane as is used for the transformation, the radial displacement can be assessed (Kraus 1997). The estimation indicated less than 4.5 cm displacement for structure elements at the maximum distance of 30 cm in front of the background area. As a result of the comparison test, differences of data between the original picture and the orthophoto were inferred to be less than 3% on average (Table 1) except for the SideLook parameters row-hole count and topline. The different results between original and rectified picture for the hole parameters and the topline are mainly caused by a little variation of SideLook settings during the picture processing, such as a slightly differently chosen threshold, producing more or fewer holes in the lowest vegetation strata and inducing black spots of the size of about one pixel in the upper part of the picture, which elongate the topline.

Altogether the calculated distortions are slight (see above) and are not very relevant to analysis stability because of the often quite heterogeneous vegetation stands and the standardisation of picture recording in VESTA, in that the same experimental design is used for all photos.

6.2 Comparison of height analysis

Most crucial are vertical distortions, which influence parameters like row denseness and vegetation height parameters such as maximum height or 90% height. In order to test the quality of SideLook height analysis, the maximum height measured in the field and the SideLook data output were compared for 500 pictures of the standard 30 cm × 100 cm areas (including plots with tall stalks). The data show a highly significant correlation (r = 0.97, linear) between the SideLook data and field height measurement, but SideLook on average overestimates the height values slightly (Fig. 3 and Table 2). Caused by the optical paths, as expected, for elements higher than the camera height the overestimation is greater than for short elements in total, but the proportional error decreases with increasing height. Using the formula $x = (y - 2.1021)/1.0748$ (results of the regression analysis for intercept and slope: standard error [0.65; 0.01]; p-values < 0.001%) extracted from the calibration curve (see Fig. 3) the SideLook data can be transformed into field data for any height value within the standard data range. Stewart et al. (2001) characterise the results of direct vegetation height measurement (estimation in the field of the level below which, e.g., 90% of biomass is growing) as most consistent and accurate in comparison to independent para-

<table>
<thead>
<tr>
<th>parameter</th>
<th>range of data (min.–max.)</th>
<th>deviation [%] ± standard deviation</th>
<th>amount of the maximum deviation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>fractal dimension</td>
<td>1.77–1.87</td>
<td>−0.05 ± 0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>column denseness</td>
<td>13–53 cm</td>
<td>−0.07 ± 4.2</td>
<td>7.8</td>
</tr>
<tr>
<td>row denseness</td>
<td>127–527%</td>
<td>−0.12 ± 4.2</td>
<td>7.8</td>
</tr>
<tr>
<td>25% height</td>
<td>3–15 cm</td>
<td>0.25 ± 3.1</td>
<td>4.9</td>
</tr>
<tr>
<td>90% height</td>
<td>18–66 cm</td>
<td>0.72 ± 1.6</td>
<td>3.3</td>
</tr>
<tr>
<td>50% height</td>
<td>7–30 cm</td>
<td>0.81 ± 2.1</td>
<td>3.9</td>
</tr>
<tr>
<td>75% height</td>
<td>13–49 cm</td>
<td>0.96 ± 1.9</td>
<td>3.7</td>
</tr>
<tr>
<td>maximum height</td>
<td>28–81 cm</td>
<td>−1.18 ± 4.4</td>
<td>9.3</td>
</tr>
<tr>
<td>hole-maximum height</td>
<td>7–41 cm</td>
<td>−1.59 ± 9.8</td>
<td>16.9</td>
</tr>
<tr>
<td>row-hole width mean</td>
<td>1–31 cm</td>
<td>−2.69 ± 12.9</td>
<td>34.3</td>
</tr>
<tr>
<td>row-hole count mean</td>
<td>16–54</td>
<td>5.38 ± 11.2</td>
<td>28.5</td>
</tr>
<tr>
<td>topline</td>
<td>3–10 cm</td>
<td>−13.03 ± 38.4</td>
<td>124.2</td>
</tr>
</tbody>
</table>
meters. Therefore an additional test with the estimated 90% height was performed. This likewise showed a good overall correlation \( r = 0.95 \) with the results of the SideLook data, although there was an overestimation or underestimation in some vegetation types.

It follows that SideLook data are robust for height measurements and can be used to analyse height parameters derived from VESTA vegetation pictures. Additionally, this method can help to remove typical false estimations of the direct method in a training stage.

### 6.3 Effects of different persons on SideLook analysis

In order to test the degree to which SideLook picture processing is independent of the person doing the processing, 30 original pictures out of 360 were chosen at random and were analysed for a set of 15 structure parameters (see Table 3) by ten persons. Decisive factors for an unproblematic analysis are good raw pictures (see Section 4.2), a well chosen threshold adaptation to the pictures’ colour spectra, and finally a standardised frame setting which will be described in detail in a further publication.

For all parameters except topline and average row-hole size a low standard deviation was found. Particularly for the often used row denseness (Barkman 1988; Curtis & Bignal 1985; Mitchley & Willems 1995; Werger et al. 1986) a very stable data output was found. The topline is very sensitive to black-pixel contamination in the upper picture part and to frame limitations excluding apical or lateral vegetation components. This parameter is as severely affected in the adjustment of threshold for transformation to a black and white picture as the average row-hole size. A slightly different adjustment may produce very small white spots in the lower picture parts (transformation of dark vegetation elements to background) or little black pixels in the upper picture area (transformation of, e.g., pollen spots on the background to vegetation). Therefore the picture processing has to be done in a standardised way to prevent the occurrence of this small pixel noise. For details of the other tested parameters see Table 3. Altogether, the dependence on personal adjustments during the picture processing is low, and the SideLook results obtained by different persons are very similar.

#### Tab. 2. Comparison of maximum height measured in the field and analysed from the pictures with SideLook for four height intervals.

<table>
<thead>
<tr>
<th>Height Interval</th>
<th>Field [cm]</th>
<th>Analysis [cm]</th>
<th>Difference [cm]</th>
<th>Difference [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height interval 61–80 cm</td>
<td>109</td>
<td>68.8</td>
<td>75.8</td>
<td>7.0</td>
</tr>
<tr>
<td>Height interval 41–60 cm</td>
<td>209</td>
<td>50.9</td>
<td>57.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Height interval 21–40 cm</td>
<td>169</td>
<td>31.9</td>
<td>36.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Height interval 1–20 cm</td>
<td>13</td>
<td>18.0</td>
<td>22.2</td>
<td>4.2</td>
</tr>
</tbody>
</table>

#### Tab. 3. Comparison of the SideLook results obtained by different persons. Average of the standard deviation (%) of 10 persons \( \times \) 30 pictures and the range of data output.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean Standard Deviation [%]</th>
<th>Range of Data [min–max]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractal Dimension</td>
<td>0.71</td>
<td>1.6–1.9</td>
</tr>
<tr>
<td>Sward Surface Height</td>
<td>2.38</td>
<td>21.9–95.8 cm</td>
</tr>
<tr>
<td>Maximum Height</td>
<td>2.41</td>
<td>45.9–116.3 cm</td>
</tr>
<tr>
<td>90% Height</td>
<td>2.53</td>
<td>19.2–90.6 cm</td>
</tr>
<tr>
<td>75% Height</td>
<td>3.36</td>
<td>12.3–82.7 cm</td>
</tr>
<tr>
<td>Column Denseness Variation</td>
<td>4.25</td>
<td>3.0–14.8 cm</td>
</tr>
<tr>
<td>Roughness</td>
<td>4.33</td>
<td>0.6–24.9 cm</td>
</tr>
<tr>
<td>Row Denseness</td>
<td>4.51</td>
<td>16.2–62.9 cm</td>
</tr>
<tr>
<td>50% Height</td>
<td>4.51</td>
<td>7.0–69.2 cm</td>
</tr>
<tr>
<td>Column Denseness</td>
<td>4.82</td>
<td>12.2–56.7 cm</td>
</tr>
<tr>
<td>Maximum Hole Size</td>
<td>6.03</td>
<td>4.0–49.8 cm</td>
</tr>
<tr>
<td>Row-Hole Count</td>
<td>7.69</td>
<td>15.2–52.3</td>
</tr>
<tr>
<td>Hole-Maximum Height</td>
<td>8.68</td>
<td>7.5–49.6 cm</td>
</tr>
<tr>
<td>Topline</td>
<td>17.40</td>
<td>1.3–14.9 cm</td>
</tr>
<tr>
<td>Average Row-Hole Size</td>
<td>17.48</td>
<td>0.9–16.5 cm</td>
</tr>
</tbody>
</table>

Fig. 3. Comparison of height values measured in the field and SideLook data output (analysis data; \( n = 500 \)).
6.4 Correlation of vegetation denseness with harvested phytomass

In a logarithmic regression (Fig. 4) a correlation of the calculated vegetation denseness with harvesting phytomass quantification (dry weight) was tested in order to obtain a quick and non-destructive method for phytomass analysis (review by Born 1990; Catchpole & Wheeler 1992). The comparison was based on a set of 32 plots representing the full range of sand vegetation, from open pioneer communities (Corynephorion) to dense and tall-grass-dominated stands (Calamagrostis epigejos plots), harvested and photographed on June 12, 2001.

A good logarithmic correlation was found (r = 0.93) for the standard plot area of 30 cm × 100 cm. An area too large for dense vegetation communities would result in an exponential curve caused by an increasing dry phytomass weight and stable vegetation denseness. On the other hand, if the test area is too small, the row denseness would not reach 100% denseness in any strata. Therefore a comparison value for phytomass standing crop higher than 3–5 cm above the ground (lowest possible picture height) can be evaluated by determining the vegetation denseness of a picture with SideLook. An even better correlation than in this test run can be found by performing the calibration in neighbouring plots of the same plant community as the photo plots. As was previously found by Roebertsen et al. (1988) and Oppermann (1989), photographic methods can therefore be used for above-ground phytomass assessment, particularly in heterogeneous vegetation when a medium accuracy is sufficient. After basic calibration harvesting procedures, picture processing will deliver values for phytomass sequences associated, for instance, with grazing impact or phenological changes. The calibration should be synchronised with the examined phenological stage of the plant community.

7. Discussion

Overall, the different parameters introduced to describe the vertical structure are robust against differences between the persons applying the method, optical distortions and technical problems (see below). Only topline and the average hole count and size are more sensitive to differences in the picture processing procedure. The lightweight equipment can be carried over a long distance, so that the method can be applied, e.g., in mountain regions. Even steep inclination has no relevance, although very rough ground can cause problems in these regions. Although it is a non-destructive method, an area around the test plot is disturbed during the photographing, which can affect the data recorded later in the year.

7.1 Time consumption

The photography can be carried out in a reasonable time: about 20 minutes are necessary for the processing of one stand (recording the picture: 8 min, image downloading and preparation for analysis: 5 min, and evaluation with the SideLook program: 8 min). Among the methods tested by Sundermeier (1999) ours can be classified as a quick technique, especially regarding the vast possibilities of parameter coverage.

If the species are known or can easily be determined, the evaluation of the percentage species cover in the open field takes about 10–20 min (depending on the species diversity). Additional investigations, e.g. concerning further textural parameters, are more time-consuming.

7.2 Influence of weather conditions

The method is independent of weather conditions except for strong winds (blurred structures will enlarge the number of pixels) or wet vegetation (water drops bend the structures down). Best results can be obtained when there is high contrast between vegetation (in full sunlight) and background (standing in line with the sunbeams, background nearly shadowed). In the case of overcast days, in gloomy situations or intense vertical sunlight at noon a photoflash is useful, so that shaded vegetation in the undergrowth is illuminated and contrasts with the background.
7.3 Sunlight reflections on plant surfaces

Problems can arise when sunlight is reflected from plant surfaces and many plant structures (e.g. blossoms or dead standing crop) have bright or light-coloured parts, since these areas will not differ from a bright background such as used by Born (1990), Roebertsen et al. (1988) and others. However, these elements and regular tinted leaves or stems contrast very well with a dark background (Riedel 2000). Furthermore, direct sunlight causes no problems in the field because shadows of plants are not recognised as vegetation structure owing to their similarity to background colour.

8. Application in model systems

8.1 Study site

Three case studies were performed in a mainly base-rich inland sand dune district near Darmstadt (northern upper Rhine valley, Germany) (Zehm 1997). According to the results of our permanent plot researches (Schawe et al. 2000; Stroh et al. 2002) the vegetation of these sand ecosystems is characterised by successional series from Corynephorion- and Koelerion glaucae communities to an Allio-Stipetum, and on base-poor stands, from Filagini-Vulpietum to Armerio-Festucetum to Cynodon dactylon stands (see Table 4). Regarding the row denseness, the typical Armerio-Festucetum still has elements of a pioneer community.

The PCA-ordination of the dataset (Fig. 5) shows a gradient of increasing vegetation denseness from the sparse Bromo-Phleetum to the dense Cynodon dactylon stands and a separation of the more vertically orientated Allio-Stipetum from the other stands. Table 4 summarises the essential differences between the six analysed communities. The most important parameter for the PCA plot arrangement is the increasing amount of vegetation denseness within the data set, so that as a whole the arrangement of the plots in the ordination follows the phytocoenological progression of succession (Schawe et al. 2002 b). Communities of consolidated soils are situated on the one side, while the Bromo-Phleetum that grows on the most initial sands (Oberdorfer 1993; Zehm 1997) is located at the opposite end.

Discussion

The Corynephorion links the different stands (Bromo-Phleetum, Armerio-Festucetum) to which it has structural similarities as well as phytosociological correspondences (Oberdorfer 1993). For instance, these may be caused by the emergence of Corynephorus canescens under increasing disturbance or succession.

The vertical structure and horizontal pattern of the Corynephorion is characterised by the height of Corynephorus canescens tufts and little gaps of bare soil in between (Oberdorfer 1993; Zehm 1997). A detailed analysis (900 measurement points within 3 m²) of a typical Corynephorion stand (Zehm 1997) showed a ssh (sward surface height) of 31.2 cm with a roughness of ±7 cm, which is close to the 95% height of 31 cm. Mainly the ssh is between 20–30 cm; only some small areas show a higher vegetation or light gaps. The spatial pattern of tussock height can be analysed to describe essential positions, e.g., for thermobiontic geophilous insects. The ssh of a stand influences e.g. the grazing behaviour of animals (Edwards et al. 1995; Porzig & Sambraus 1991) and is in turn affected by grazing (see Section 8.2.3) if the dominant plant species are consumed by the grazing animals.

With the proposed method it is possible to elaborate a very detailed description of plant community stands and to isolate the structural parameters characterising the communities, particularly in comparison to adjacent vegetation stands.
Fig. 5. PCA of six vegetation units (n = 56 stands) and main parameters influencing the data spread (50% height, veg. dens. = vegetation denseness, row dens. 20 cm = row denseness 0–20 cm, row dens. 40 cm = row denseness 20–40 cm). Ordination is based on the structural similarity according to: row denseness, maximum vegetation height, vegetation denseness, 75, 50, 25% height (axis 1: 63%; axis 2: 19%; axis 3: 8% of variance).

Tab. 4. Row denseness, maximum height and vegetation denseness of six sand-vegetation communities (± standard deviation). The row denseness is calculated as average of height classes of 10 cm height.

<table>
<thead>
<tr>
<th>vegetation type</th>
<th>Bromo-Phleum</th>
<th>Coryne-phorion</th>
<th>Filagin-Vulpitum</th>
<th>Armerio-Festucetum</th>
<th>Cynodon dactylon</th>
<th>Allio-Stipetum</th>
</tr>
</thead>
<tbody>
<tr>
<td>vegetation denseness [%]</td>
<td>1130 ± 212</td>
<td>1545 ± 421</td>
<td>2245 ± 180</td>
<td>2311 ± 307</td>
<td>3997 ± 724</td>
<td>3656 ± 439</td>
</tr>
<tr>
<td>maximum height [cm]</td>
<td>25.1 ± 4.0</td>
<td>42.0 ± 6.5</td>
<td>36.9 ± 2.0</td>
<td>54.0 ± 4.61</td>
<td>65.8 ± 8.2</td>
<td>81.3 ± 5.3</td>
</tr>
<tr>
<td>81–90 cm (% cover)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.5 ± 3.0</td>
</tr>
<tr>
<td>71–80 cm (% cover)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.1 ± 0.3</td>
<td>7.9 ± 5.5</td>
</tr>
<tr>
<td>61–70 cm (% cover)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.3 ± 5.2</td>
<td>19.6 ± 6.3</td>
</tr>
<tr>
<td>51–60 cm (% cover)</td>
<td>0</td>
<td>0.6 ± 1.1</td>
<td>0.02 ± 0.1</td>
<td>10.7 ± 7.8</td>
<td>36.2 ± 30.8</td>
<td>37.2 ± 9.3</td>
</tr>
<tr>
<td>41–50 cm (% cover)</td>
<td>0.02 ± 0.1</td>
<td>6.7 ± 9.0</td>
<td>3.5 ± 4.9</td>
<td>24.8 ± 7.5</td>
<td>71.4 ± 21.5</td>
<td>51.3 ± 10.5</td>
</tr>
<tr>
<td>31–40 cm (% cover)</td>
<td>1.8 ± 3.0</td>
<td>31.1 ± 14.9</td>
<td>38.2 ± 19.9</td>
<td>36.6 ± 9.2</td>
<td>91.6 ± 5.2</td>
<td>65.5 ± 9.9</td>
</tr>
<tr>
<td>21–30 cm (% cover)</td>
<td>28.6 ± 24.1</td>
<td>46.9 ± 14.5</td>
<td>86.8 ± 10.1</td>
<td>63.5 ± 16.0</td>
<td>93.6 ± 1.9</td>
<td>73.9 ± 8.5</td>
</tr>
<tr>
<td>11–20 cm (% cover)</td>
<td>83.4 ± 11.9</td>
<td>69.3 ± 15.2</td>
<td>96.0 ± 2.5</td>
<td>94.6 ± 5.5</td>
<td>91.7 ± 3.6</td>
<td>81.6 ± 7.1</td>
</tr>
<tr>
<td>0–10 cm (% cover)</td>
<td>83.4 ± 11.9</td>
<td>69.3 ± 15.2</td>
<td>96.0 ± 2.5</td>
<td>94.6 ± 5.5</td>
<td>91.7 ± 3.6</td>
<td>81.6 ± 7.1</td>
</tr>
</tbody>
</table>
8.2.2 Analysis of phenological dynamics: vertical structure and texture of the Filagini-Vulpietum

Plants are well known to undergo phenological changes, e.g. the periodic change of the flowering of different species in defined plant communities during the seasons and the co-phenology of anthophilous insects (e.g. Kratochwil 1983, 1988), but little is known about the spatial phenology of vegetation structure. One of the few publications is that of Oppermann (1989), presenting data for some plant communities under mowing management.

**Textural characteristics of the Filagini-Vulpietum (species denseness)**

On five permanent plots pictures of a Filagini-Vulpietum (Thero-Airon) were taken in May, June, July and September. The floristic combination is dominated by small therophytes. The analysis of species denseness shows that the phenology of the Filagini-Vulpietum can be divided into three chronophases:

- Spring: The structure is dominated by very few species like *Poa bulbosa* and some winter annuals, forming a low structure rich in holes.
- Early summer: the many spring-germinating therophytes like *Vulpia myuros* and winter annuals such as *Medicago minima* form a low, dense structure.
- Late summer: A heterogeneous stand with some tall individuals of *Salsola kali* ssp. *tragus* or *Conyza canadensis* rises above the remnants of the spring/early summer aspect.

During these five months the contribution of species with lower than 10% share of the total increases from 27% to 45% cover, and no species accounting for more than 41% of the total can be found at all at the end of the growing season (September).

**a) Phenology of the row denseness**

Results

During the whole season the Filagini-Vulpietum is characterised by a large amount of small plants with nearly the same low height, which therefore as a whole yield flat partitioning curves (Fig. 6). In May most of the vegetation denseness in the examined plots was accumulated below 10 cm height and only some inflorescences were taller than 15 cm. By June the growth of therophytes has formed a dense layer below 15 cm height.

Communities in moist or nutrient-rich areas reach a phytomass peak between summer and late autumn (e.g. Arrhenatheretum: Oppermann 1989). As in other plant communities on xeric sites, the Filagini-Vulpietum has a phenological peak in springtime and early summer. The maximum was detected in June. In July the breakdown of vertical structures began, and the denseness had fallen to 83% of that in June. The September situation is intermediate between this and the starting conditions in May.

**Discussion**

The vegetation denseness corresponds to the results obtained with the “vegetation stratimeter” (see Section 3) of Oppermann (1989). In partitioning curves generated with the help of this stratimeter Kratochwil (1989) identified structural differences of some grassland communities and the influence of mowing and fertilisation. An interpretation of the partitioning curve describes the heterogeneity of the plant element sizes within a stand: e.g., a steeply sloped curve indicates a high heterogeneity, whereas a gently sloped curve is a sign of a uniform canopy.

**b) Impediment to movement and row-hole data**

(row-hole size, row-hole count, hole-maximum height)

Results

The “impediment to movement” (Schaefer 1992) is defined as the resistance a small animal (arthropod or vertebrate) has to overcome in order to cross a vegetation stand. It depends on the number and size of the elements impeding locomotion (Heydemann 1957; Schaefer 1992). The combination of hole size and hole number can be used to analyse the spatial resistance of a phytocoenosis.

The Filagini-Vulpietum forms a low vegetation with a high denseness and density below the height at which
Orthopteroidea reflects the “spatial resistance”. In high, dense vegetation the animal simply drops down into the dense ground vegetation or makes long flights. In vegetation that is dense but low, Caelifera and Ensifera (like e.g. *Chorthippus mollis*) begin with a steep jump (take-off angle between 70–90°) in order to exceed the ssh as quickly as possible. Only in very open vegetation can a flat starting angle of about 15° be observed (e.g. *Oedipoda caerulescens*), because in this case no vegetation elements hamper the escape flight (Zehm 1996). Furthermore, the search for mating partners is based mostly on vision, whereas grasshoppers in dense vegetation use progressively more intensive stridulation according to the vegetation density/denseness.

Following the spatial analysis (row denseness, row-hole data) the species and processes causing the structural changes can be characterised with the additional data of the species denseness.

### 8.2.3 Analysis of disturbance dynamics: grazing impact (ssh, 90% height, row denseness, fractal dimension)

#### Subject and results

This example refers to a former Allio-Stipetum which is currently dominated by *Calamagrostis epigejos* (with more than 20% species denseness in the plots). In the meantime the plot is grazed by sheep to reverse the successional progresses (for the biology of *Calamagrostis* cf. Rebele & Lehmann 2001). The area is grazed with high intensity over a short period of time during the year. Nevertheless, it is an extensive grazing regime with less than 2.3 sheep/ha/yr. In the grazed plot an increasing segregation of vegetation cover and height development in the grazed and ungrazed plots was found. In the grazed area the height parameters drop whereas in the undisturbed control plot a little upgrowth can be discerned (Fig. 8). The row denseness (Table 6) increases in all strata in the control plots and decreases in the grazed plots beneath 60 cm height (although above 60 cm it increases here as well). In the grazed plots the standard deviation of ssh and the 90% height increases, owing to the grazing impact (Fig. 8), so that the stand structure becomes more heterogeneous. A decrease of the fractal dimension was found in the grazed plots, from 1.80 ± 0.02 (standard deviation) before to 1.77 ± 0.05 after grazing, whereas the control plots were stable at 1.83 ± 0.02 at all times.

#### Discussion

For long-term conservation of sand ecosystems cyclic moderate disturbances are important factors (Jentsch & Beyerlag 2003; Jentsch et al. 2002). Apart from

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**Tab. 5. Synopsis of the hole data for the Filagini-Vulpietum (± standard deviation).**

<table>
<thead>
<tr>
<th>Average row-hole size [cm]</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.4 ± 6.7</td>
<td>3.8 ± 1.1</td>
<td>8.4 ± 3.8</td>
<td>8.7 ± 2.8</td>
<td></td>
</tr>
<tr>
<td>Average row-hole count [n]</td>
<td>88.5 ± 5.0</td>
<td>63.3 ± 8.5</td>
<td>50.1 ± 6.1</td>
<td>74.1 ± 4.0</td>
</tr>
<tr>
<td>Hole-maximum height [cm]</td>
<td>5.2 ± 1.1</td>
<td>16.4 ± 1.5</td>
<td>14.0 ± 1.2</td>
<td>12.0 ± 1.4</td>
</tr>
</tbody>
</table>

---

**Fig. 7.** Row-hole count of a Filagini-Vulpietum in relation to the vegetation height during the season. At the point of the maximum row-hole count the height of the hole-maximum height can be extracted.

---

Discussion

The Filagini-Vulpietum has a high spatial resistance near the ground, in particular for flying insects, but on the bare ground surface (mainly without a moss/lichen cover) the community is well traversable for small surface-dwelling insects like ants or small ground beetles. During the growth period the change in row-hole size and number is comparable to the shift of the row denseness (Results 8.2.2a). The escape behaviour of

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Orthopteroidea reflects the “spatial resistance”. In high, dense vegetation the animal simply drops down into the dense ground vegetation or makes long flights. In vegetation that is dense but low, Caelifera and Ensifera (like e.g. *Chorthippus mollis*) begin with a steep jump (take-off angle between 70–90°) in order to exceed the ssh as quickly as possible. Only in very open vegetation can a flat starting angle of about 15° be observed (e.g. *Oedipoda caerulescens*), because in this case no vegetation elements hamper the escape flight (Zehm 1996). Furthermore, the search for mating partners is based mostly on vision, whereas grasshoppers in dense vegetation use progressively more intensive stridulation according to the vegetation density/denseness.

Following the spatial analysis (row denseness, row-hole data) the species and processes causing the structural changes can be characterised with the additional data of the species denseness.

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**Discussion**

For long-term conservation of sand ecosystems cyclic moderate disturbances are important factors (Jentsch & Beyerlag 2003; Jentsch et al. 2002). Apart from
Fig. 8. Comparison of structure parameters of three grazed versus three ungrazed plots at two points in time (July 1, 2000 and Sept. 4, 2000) based on 1-cm interval analysis. The plots can be classified as a former Allio-Stipetum currently dominated by *Calamagrostis epigejos*. ssh = sward surface height, 90% = 90% height, denseness = column denseness, error bars = standard deviation.

Tab. 6. Grazing effects on the row denseness of a ruderalized Allio-Stipetum dominated by *Calamagrostis epigejos*.

<table>
<thead>
<tr>
<th>height above ground</th>
<th>row denseness of the grazed plot [%]</th>
<th>row denseness of the check plot [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>before grazing</td>
<td>after grazing</td>
</tr>
<tr>
<td>61–80 cm</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>41–60 cm</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>21–40 cm</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>1–20 cm</td>
<td>89</td>
<td>71</td>
</tr>
</tbody>
</table>

9. Conclusions

The presentation of the new method, its evaluation and the results of the case studies have shown that VESTA in combination with the software tool SIDELOOK has the following main benefits: The method is

- independent of the person implementing it
- robust against picture distortions, especially for height parameters
- not very time-consuming
- a non-destructive method and therefore applicable for analysis of the time axis
- a standardised method which can be used for various ecological purposes, such as scientific studies or nature conservation management.

But although the method is non-destructive for the test area, the surrounding area is more or less disturbed. Moreover, some parameters are not independent of one another, but out of the possible set of parameters a useful choice of parameters for the research aim can be extracted. Vegetation structure below 2–5 cm above ground cannot be well depicted. For an investigation of the structure of lower strata (down to 1 cm) the “Structure Measuring Tube” (according to Sundermeier 1999) is recommended. Depending on the aim of the research a simpler data-collection process may be sufficient, e.g. for direct measurements of the 90% height (Sections 3 and 6.3).

VESTA can be used for a wide range of investigation targets in pioneer and grassland communities (see above). It is possible to

- describe vegetation stands in a multiparameter approach (e.g. classification of structural units, strata characterisation)
- analyse dynamic processes (e.g. phenology, succession, grazing or fertilisation impact)
- work out biocoenotic and abiotic connections (e.g. relation to the presence of arthropod coenosis or to temperature; Barkman & Stoutjesdijk 1987)
- describe the reasons for structural modifications based on plant species denseness shifts (e.g. growth forms, morphological traits).

Apart from these points a long-term aim will be to compare vertical structure data from a wide range of different vegetation types and different geographical regions.
Acknowledgements

This work was partly supported by the BMBF-project “Inland sand-ecosystems: dynamics and restitution” (FKZ 01LN0003), and the nature conservation authority of the district Darmstadt-Dieburg. We should also like to acknowledge Dipl.-Ing. K. Zimmermann for the help regarding the relevance of distortions and Dr. C. Storm for statistical advice. Access to the sites was kindly granted by the Regierungspräsidium Darmstadt. Thanks to M. Beil, S. Bergmann, S. Häfele, N. Jährling, R. Koller, E. Mählmann, S. Müller, M. Röth, and K. Rottmann, for SideLook test runs.

Nomenclature

Nomenclature follows Wisskirchen & Haeupler (1998); plant community classification is according to Oberdorfer (1993, 2001) and Zehm (1997).

Program source

The software tool SideLook can be downloaded as shareware at http://www.appleco.de.

References


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