Journal of Vegetation Science 14: 815-821, 2003
© IAVS; Opulus Press Uppsala.

Scale-dependent variation in visual estimates of grassland plant cover

Klimeš, Leoš

Institute of Botany, Section of Plant Ecology, Dukelská 135, CZ–379 01 Třeboň, Czech Republic; Fax +0420384721136; E–mail klimes@butbn.cas.cz

Abstract. Plant cover was visually estimated by five observers, independent of each other, in a species-rich grassland in the Bílé Karpaty Mts., southeastern Czech Republic, in seven plots ranging from 0.001 to 4 m^2. Variation of total plant cover among the observers was high at small scales: 0.001 - 0.016 m^2; coefficient of variation, CV = 35 to 45%, but much lower at larger scales: 0.06 - 4 m^2; CV = 7 to 15%. Differences between visual estimates of plant cover of individual species made by different observers were affected by plot size, total cover and morphology of particular plants. CV of the cover of individual species ranged from 0 to 225% and decreased with increasing plot size. For abundant plants the CV attained ca. 50%, independent of plot size. In spite of a very high number of sterile plants with similar leaf morphology and colour, the observed variation in cover estimates in the studied grassland was comparable with results reported from other vegetation types. Differences between estimates by individual observers were often larger than usual year to year changes in undisturbed grasslands. Therefore, I suggest that to avoid difficulties in the interpretation of results based on plant cover data obtained from visual estimates, several observers should always work together, adjusting their extreme estimates.

Keywords: Sampling error; Spatial scale; Species-rich meadow.

Nomenclature: Marhold & Hindák (1998).

Introduction

In spite of the progress in plant ecological methods, visual estimates of plant cover are still used both in descriptive studies and in experiments carried out in plant ecology. In descriptive vegetation (phytosociological) studies visual estimates of plant cover belong to the most frequently used descriptors. The main reason for their attractiveness lies in the very low cost of the data obtained in this way, both in terms of time and equipment. Moreover, these estimates are not biased by size and distribution of individuals (Mueller-Dombois & Ellenberg 1974; Floyd & Anderson 1987). Therefore, visual estimates of plant cover are frequently used, even in cases where exact and unbiased results are needed (e.g. Tilman 1999; Symstad 2000). In plant communities with an open canopy and little overtopping alternative methods are available (e.g. image analysis and point intercept method, see Bråkenhielm & Liu 1995; Dietz & Steinlein 1996; Liu & Bråkenhielm 1996; Röttgermann et al. 2000; Vanha-Majamaa et al. 2000). In contrast, for more complicated structures no simple quantitative method for an estimation of plant cover has been developed (Everson et al. 1990; Stampfli 1991; Vanha-Majamaa et al. 2000).

The fact that visual estimates of plant cover are unrepeatable is well known and is mentioned in most textbooks on vegetation ecology (e.g. Kershaw 1973; Greig-Smith 1983; Kent & Coker 1992). However, in my experience, most users of visual plant cover data believe that their estimates are reliable and consistent across plant communities and over time, or at least biased systematically, meaning that an observer makes the same errors in different vegetation types and seasons, and these errors are independent of plant species identity (cf. Dierschke 1994). For example, Kent & Coker (1992) claim that "problems of subjectivity [with visual estimates of plant cover] may have been overemphasized".

Several authors have compared estimates of plant abundance obtained by using different methods (Daubenmire 1959; Hanley 1978; Floyd & Anderson 1987; Smartt et al. 1974, 1976; Vanha-Majamaa et al. 2000), but they usually focused on open canopy vegetation, such as early successional stages or disturbed nutrient-poor habitats, where estimation of plant cover by eye is relatively easy and expected errors are small. In contrast, surprisingly little has been done to assess the bias of plant cover estimates in plant communities with closed canopies, where more serious methodological problems can be expected, and to assess the biases made by different observers.

There are some indications that the error may vary among plant community types, e.g. according to the length of the grass (Hope-Simpson 1940). Visual estimates may also substantially differ between individual observers (Bråkenhielm & Liu 1995) and between repeated estimates of the same observer (van Hees & Mead 2000). In an early report, Smith (1944) suggested that training may reduce this error to some extent. However, several contradictory results have been published. For example, it is not clear whether estimates of low cover values are more biased than middle or high values (Kennedy & Addison 1987) or if the opposite is the case (Sykes et al. 1983). The supposedly large errors in visual estimates of plant cover may complicate interpretation of differences between vegetation types and experimental treatments reported in the literature. Kennedy & Addison (1987) suggested that plant cover changes less than 20% can be attributed to estimation errors. Unfortunately, it is not known how far this conclusion based on records of a single observer in 1 m^2 squares situated in a species-poor forest is valid for data obtained by several independent observers and in species-rich communities with a more complicated structure. For example, grasslands which usually differ markedly from forests by their higher total plant cover, species richness and variation in plant morphology, may lead to different errors in visual plant cover estimates (Hope-Simpson 1940). Similarly, virtually nothing has so far been published on the effects of scale, species richness, vegetation structure and proportion of plants with different leaf forms on the errors in visual estimates.

In this communication I present results of a simple study focused on variation in visual plant cover estimates between several observers. As there is no easy method providing non-biased estimates of plant cover in species-rich plant communities with a more or less closed canopy, I did not compare estimates by individual observers with any reference, so that the absolute errors made by individual observers remain unknown. The study was performed in a grassland where only ca. four species per 0.001 m^2 occur. In contrast, at large scales the studied grassland belongs to the most species-rich in Europe: 68 species have been found per 1 m^2 and 85 species per 4 m^2 (Klimeš et al. 2001). Visual cover estimates are particularly difficult to obtain in this vegetation type due to the high number of species with similar morphology of above-ground parts, of which most are usually sterile and partly overlapping. Two problems were studied in detail: (1) the effect of spatial scale on variation in plant cover estimates between observers and (2) systematic species specific bias in plant cover estimates at various scales.

The study area

The study area is situated in the National Nature Reserve of Čertoryje, Bílé Karpaty Mts., southwestern Czech Republic (48° 54' N, 17° 25' E). The experimental plots were located on a SW facing slope at 440 m a.s.l. with an inclination of 5°, in a grassland with scattered *Quercus robur* trees (see Klimeš 1999 and Klimeš et al. 2001 for details). The grassland is mown once a year and has not been fertilized in recent decades. The following species had a mean cover of 2% or more in June 1998: *Bromus erectus* (21%), *Carex montana* (16%), *Molinia arundinacea* (6%), *Cirsium pannonicum* (4%), *Prunella*

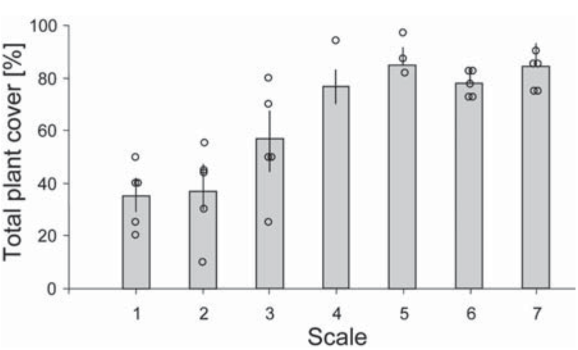

Fig. 1. Estimates of total plant cover (mean ± SD) in seven plots. Circles denote estimates by individual observers. 1 = 0.001, 2 = 0.004, 3 = 0.016, 4 = 0.063, 5 = 0.25, 6 = 1, 7 = 4 m^2.

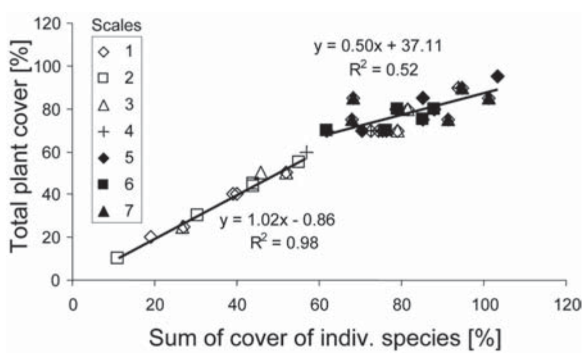

Fig. 2. Relationship between sum of cover estimates of individual species and estimates of total plant cover for sum of cover estimates of individual species < and > 60 %.

grandiflora (3%), *Viola hirta* (2%), *Potentilla alba* (2%) and *Brachypodium pinnatum* (2%) (estimated in 25 plots, 0.5 m^2 each, situated 20 m from the studied area; Klimeš et al. 2001). Maximum above-ground biomass was ca. 250 $g.m^{-2}$ in 1998.

Methods

I established seven non-overlapping plots in an 8 m × 8 m area of homogeneous and species-rich grassland. The largest plot was 4 m^2, the next plots were always 4 × smaller than the previous one, so that the smallest plot was ca. 9.8 cm^2 (0.001 m^2). The three smallest plots were circular, with a diameter of ca. 3.5, 7.1 and 14.1 cm, respectively, and delimited by a wire. The medium-size plots were quadrats delimited by a rope and were 25 cm × 25 cm and 50 cm × 50 cm in size. The two largest plots, also delimited by a rope, were rectangles, 0.5 m × 2 m and 0.5 m × 8 m in size. The resulting scale is:

Scale	1	2	3	4	5	6	7
Area (m^2)	0.001	0.004	0.016	0.062	0.25	1	4

I used narrow rectangles because the observers were not allowed to enter the plots to prevent trampling and other disturbance and plants in plots wider than ca. 0.5 m cannot be censused without entering the plots. Therefore, plant cover estimates were made while lying or kneeling on the ground.

To minimize the effect of experience and training, the observers spent a week identifying plants and making cover estimates in the surroundings of the experimental plots before the experiment started. They repeatedly discussed methodological problems associated with plant cover estimates and adjusted their estimates, if necessary. The five observers were either professional botanists or Ph.D. students with at least three years experience in floristics of the Bílé Karpaty Mts. Therefore, their background was similar. During the experiment, performed in June 1998, each observer worked independently in each of the seven plots. The order of the plots was not fixed. Some observers did their work in a single day, others over two days. Sampling time per plot nor for all seven plots was limited.

Individual observers estimated plant cover (1) for the whole stand and (2) for individual species of vascular plants. Plant cover was defined as the vertical projection of all living aerial parts of plants as percentage of the total plot area (Westhoff & van der Maarel 1973). Thus, the cover of all individual species together should be higher than the estimate of total plant cover if some overlapping takes place. Individual observers used cover scales which they considered appropriate for a given vegetation type and plot. The number of cover classes was not fixed. Cover values below 1% were arbitrary assigned to 0.5%. Data analysis was performed using a data set from which suspicious records not confirmed by me at the end of the experiment were removed.

The recorded species were classified according to leaf width into three categories: narrow-leaved plants (grasses, graminoids) with leaf or leaflet length / leaf or leaflet width (Leaf ratio = LR) > 20, intermediate plants with 5 < LR < 20 and broad-leaved plants with LR < 5. Cover of species not recorded in a particular plot by all observers was set to zero in species lists of observers who did not record them.

I tested three hypotheses to assess the role of factors potentially causing systematic biases by some observers. 1: By comparing cover values estimated by individual observers with the group mean based on cover estimates by other observers for individual plot sizes I tested whether exceptional values of cover estimates are associated with broad or narrow leaves. The exceptional values of plant cover recorded by individual observers in a plot were defined as estimates significantly differing from a group mean calculated from estimates of remaining observers. 2: That the amount of bias in cover estimates is correlated with plant frequency; frequent plants, occurring in most plots, could be over-weighted or under-weighted by some observers. Then the difference in plant cover estimated by individual observers and the group mean based on estimates by other four observers was calculated and the relationship between this difference and overall plant frequency, estimated across plot sizes and observers, was calculated for individual plot sizes using regression analysis. Hypothesis 3, similar to the previous one, was tested for plant cover.

Results

Total plant cover

The group mean of total plant cover estimates (calculated over observers) was ca. 40% in the two smallest plots and ca. 80% in the three largest plots. In the two remaining plots the estimates were intermediate. The estimates of total plant cover significantly differed among observers (F = 324.1, P < 0.001; two-way ANOVA without replication). The range of the observed values was the highest at the medium scale (0.0156 m^2) and decreased towards both extremes of plot size (Fig. 1). At small scales (0.001-0.016 m^2) the coefficient of variation (CV) of total plant cover among observers ranged from 35 to 45%, whereas at larger scales (0.06-4 m^2) it was much lower (7-15%). A similar pattern was obtained for plant cover totalled for all species recorded in different plots. Therefore, the correlation between the sum of individual plant species cover estimates and total plant cover was strong and the slope of the regression line for values lower than 60% was close to 1.0 (Fig. 2). However, high values of the sum of cover estimates were associated with low estimates of total plant cover. This indicates that in plots with a total cover of more than 60% individual plant species cover estimates reflected some overtopping of plant organs whereas in plots with a total cover of 60% or less, overtopping did not affect the estimates.

Plant cover of individual species

As no cover scale was recommended to the observers it is not surprising that they used different scales. Above a plant cover of 10% all observers used steps of 5% whereas below 10% most of them used steps of 1%. The total number of cover classes varied among observers with a factor two, ranging from 8 to 16.

Altogether, 112 species of vascular plants were recorded in the seven plots by five observers. Most of them were represented by a few individuals so that their cover was very low (Table 1). The highest values of plant cover were ca. 30% but most values were < 5%.

Table 1. Visual plant cover estimates from five observers in plots differing in size from 0.001 - 4 m^2. Mean (min.-max.) are given for species which had a mean cover of 1 % or more in at least one plot.

Plot (scale)	1 = 0.001 m^2	2 = 0.004 m^2	3 = 0.016 m^2	4 = 0.062 m^2	5 = 0.25 m^2	6 = 1 m^2	7 = 4 m^2.
Narrow-leaved							
Anthoxanthum odoratum	-	-	0.2 (0 – 1)	< 0.1 (0 – 0.1)	0.5 (0.1 – 1)	0.3 (0.1 – 1)	1.6 (1 – 2)
Brachypodium pinnatum	-	2.2 (0 – 5)	4.6 (3 – 5)	1.8 (1 – 3)	0.8 (0 – 3)	1.2 (1 – 2)	2 (1 – 5)
Briza media	-	0.2 (0 – 1)	1.4 (0 – 3)	< 0.1 (0 – 0.1)	0.8 (0.1 – 1)	0.6 (0.1 – 1)	1.4 (1 – 3)
Bromus erectus	-	0.4 (0 – 1)	8.6 (3 – 20)	5 (0 – 15)	9.4 (5 – 15)	11 (5 – 20)	12 (5 – 20)
Carex caryophyllea	5 (0 – 10)	0.2 (0 – 1)	2.8 (0.1 – 5)	1 (0 – 2)	< 0.1 (0 – 0.1)	2.6 (0.1 – 5)	2 (0.1 – 5)
Carex montana	1 (0 – 5)	-	0.8 (0 – 3)	17 (10 – 25)	30 (15 – 55)	18 (10 – 35)	13 (7 – 25)
Carex panicea	-	2.4 (0 – 10)	1.4 (0 – 5)	0.2 (0 – 1)	3 (2 – 5)	0.1 (0 – 0.1)	< 0.1 (0 – 0.1)
Carex tomentosa	-	2.4 (0 – 10)	-	0.6 (0 – 1)	0.2 (0 – 1)	0.2 (0 – 1)	< 0.1 (0 – 0.1)
Danthonia alpina	-	2.2 (0 – 5)	2.4 (0 – 10)	< 0.1 (0 – 0.1)	< 0.1 (0 – 0.1)	0.1 (0 – 0.1)	< 0.1 (0 – 0.1)
Danthonia decumbens	-	0.6 (0 – 3)	0.2 (0 – 1)	0.4 (0 – 1)	0.6 (0.1 – 1)	1 (0.1 – 2)	1.8 (0.1 – 4)
Festuca rupicola	-	< 0.1 (0 – 0.1)	-	-	1 (0.1 – 2)	0.6 (0 – 2)	1.6 (1 – 3)
Molinia arundinacea	-	-	2.2 (0.1 – 5)	3.8 (2 – 7)	8 (5 – 10)	5 (5 – 5)	3.2 (2 – 5)
Intermediate-leaved							
Achillea collina	2 (0 – 5)	-	0.2 (0 – 1)	0.6 (0.1 – 1)	< 0.1 (0 – 0.1)	0.1 (0.1 – 0.1)	0.1 (0.1 – 0.1)
Carlina acaulis	-	-	1.2 (0 – 5)	-	-	-	-
Cirsium arvense	-	-	1.2 (0 – 5)	-	-	-	-
Filipendula vulgaris	-	-	-	4.4 (2 – 6)	0.6 (0 – 2)	0.6 (0.1 – 1)	1.2 (1 – 2)
Inula hirta	-	-	-	6.2 (2 – 10)	0.6 (0 – 3)	1.6 (0.1 – 3)	1.8 (1 – 3)
Inula salicina	-	-	-	-	1 (0 – 3)	2 (0.1 – 4)	1.4 (1 – 2)
Jacea pratensis	-	-	-	1.8 (0 – 5)	-	-	0.5 (0.1 – 1)
Leontodon hispidus	0.2 (0 – 1)	6.2 (1 – 10)	1.3 (0.1 – 5)	1.4 (0 – 4)	0.8 (0.1 – 1)	0.8 (0.1 – 1)	1.2 (0.1 – 2)
Lotus corniculatus	10.6 (3 – 20)	-	-	-	0.3 (0.1 – 1)	0.5 (0.1 – 1)	0.1 (0.1 – 0.1)
Plantago lanceolata	-	-	1 (0.1 – 2)	0.1 (0 – 0.1)	0.5 (0.1 – 1)	0.5 (0.1 – 1)	0.3 (0.1 – 1)
Broad-leaved							
Betonica officinalis	-	-	-	-	-	0.4 (0 – 1)	1.2 (1 – 2)
Chamaecytisus virescens	-	-	-	-	-	1.2 (0.1 – 3)	0.3 (0.1 – 1)
Cirsium pannonicum	-	0.4 (0 – 1)	0.2 (0 – 1)	7 (5 – 10)	2.8 (1 – 5)	2.6 (1 – 5)	5.8 (3 – 10)
Crepis praemorsa	-	0.4 (0 – 2)	0.2 (0 – 1)	1 (0 – 2)	-	0.4 (0 – 1)	0.4 (0 – 1)
Knautia kitaibelii	-	-	-	-	< 0.1 (0 – 0.1)	-	2 (1 – 3)
Linum catharticum	-	2 (0 – 5)	0.5 (0.1 – 1)	0.5 (0.1 – 1)	0.5 (0.1 – 1)	0.1 (0.1 – 0.1)	0.1 (0.1 – 0.1)
Peucedanum cervaria	-	-	-	-	-	0.6 (0.1 – 1)	1.2 (1 – 2)
Plantago media	-	-	-	3.4 (2 – 5)	2.2 (1 – 3)	0.6 (0 – 2)	1.1 (0.1 – 2)
Potentilla alba	-	2.6 (0 – 10)	-	-	1 (0 – 2)	1.6 (0.1 – 3)	1.8 (0.1 – 3)
Potentilla erecta	-	-	1 (0 – 3)	-	0.3 (0.1 – 1)	0.3 (0.1 – 1)	0.1 (0.1 –0.1)
Potentilla heptaphylla	-	-	1.4 (1 – 3)	0.4 (0 – 1)	0.2 (0 – 1)	0.3 (0.1 – 1)	0.1 (0.1 –0.1)
Primula veris	-	-	-	3.2 (1 – 5)	1.2 (0.1 – 3)	1.2 (1 – 2)	0.8 (0.1 – 2)
Prunella grandiflora	-	-	2.4 (0.1 – 5)	2 (1 – 3)	2.2 (1 – 4)	10 (3 – 15)	8.6 (5 – 10)
Ranunculus polyanthemos	-	-	-	1.4 (1 – 2)	0.1 (0 – 0.1)	0.1 (0 – 0.1)	0.1 (0.1 –0.1)
Salvia pratensis	-	-	-	3.2 (1 – 5)	1.8 (1 – 3)	0.8 (0 – 2)	0.5 (0.1 – 1)
Teucrium chamaedrys	-	13.4 (2 – 20)	-	1.2 (1 – 2)	0.4 (0 – 1)	0.3 (0.1 – 1)	< 0.1 (0 – 0.1)
Veronica teucrium	-	-	-	1.6 (0.1 – 3)	-	0.4 (0 – 1)	0.1 (0.1 –0.1)
Viola hirta	16 (10 – 20)	0.8 (0 – 1)	20 (5 – 30)	2.2 (0.1 – 4)	9 (5 – 15)	1.8 (0.1 – 5)	3.6 (2 – 10)

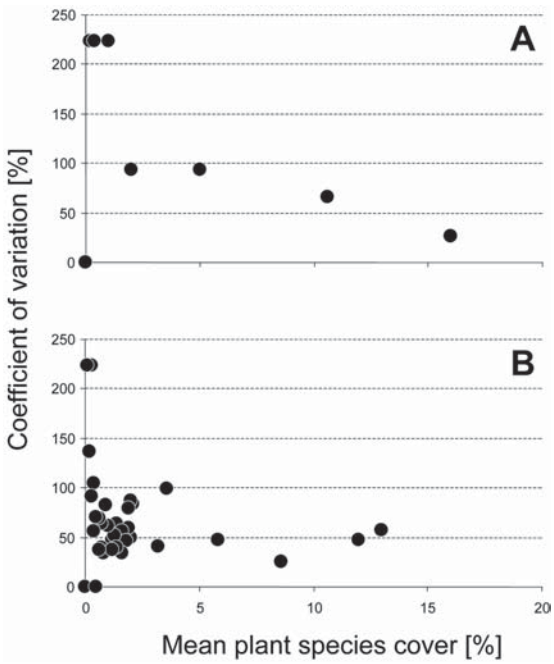

Fig. 3. The relationship between group mean of plant cover and coefficient of variation calculated over observers for the smallest **(A)** and the largest **(B)** plot.

Correlations between plant cover estimates by different observers in individual plots were always significant ($P < 0.05$), with correlation coefficients ranging from 0.65 to 0.99. Some plant cover estimates made by individual observers were very similar. For example, cover estimates of *Prunella grandiflora* in the 4 m^2 plot ranged from 5 - 10%, of *Molinia arundinacea* in the same plot from 2 - 5% and in the 1 m^2 plot all observers estimated the cover of this grass to be 5%. In other cases a considerable range of values was recorded. The cover of *Bromus erectus* in the 1 and 4 m^2 plots was estimated between 5 and 20%, of *Carex montana* in the 0.25 m^2 plot between 15 and 55% and of *Viola hirta* in the same plot between 5 and 15%. In small plots, the range was sometimes even wider. For *Teucrium chamaedrys* it was between 2 and 20% in the 0.004 m^2 plot and for *V. hirta* between 5 and 30% in the 0.016 m^2 plot. (Table 1).

CVs calculated for plant cover estimates of individual species ranged from 0 to 225% among observers. No variation (CV = 0) was found in plants with a mean cover < 1% only. The CV reached its maximum for plants with a cover < 1% and decreased with increasing group mean of plant cover (Fig. 3). In the most abundant plants the CV was ca. 50%, independent of plot size.

Bias by individual observers over spatial scales and across species

From the available data a consistent direction in bias made by observers could not be detected because no independent measure of plant cover was available. However, it is interesting to look more closely at exceptional values of cover estimates made by individual observers. I expected that exceptional values of cover estimates are associated with broad or narrow leaves. Only one result out of 35 tests was significant: one observer over estimated the cover of broad-leaved plants at the largest plot size ($P < 0.02$; one-way ANOVA). Considering the 5% proportion of significant tests based on random data, the effect of leaf shape on extreme values of cover estimates was negligible. The amount of bias in cover estimates was not correlated with plant frequency in any case. The third hypothesis, suggesting a correlation with plant cover, was not confirmed because only one significant result was obtained which is less than expected on a random basis.The analysis of cover of individual plants across plot size had a different pattern. Out of the 112 species found in the plots, 13 species received higher or lower values than the group mean calculated from estimates of the other four observers, by at least one observer. Among these 13 species narrow-leaved plants and broad-leaved plants were over-represented (six species in each category) and the remaining (intermediate) plants were under-represented (one species; $P < 0.0001$; chi^2 test). However, no leaf width category was consistently over or under represented in all biased estimates.

Discussion

Total cover

Total cover is of considerable importance because it indicates the intensity of competition for light and utilization of space above the ground. It is not clear whether the high variation observed at smaller scales was caused by the scale itself, because group means of total cover were also lower at small scales. The lower group means of total cover obtained for smaller plots need not reflect a real trend. As no independent measure of plant cover was available, a systematic bias towards lower values in smaller plots by all five observers could explain it as well. In larger plots, where plant cover was relatively high, variation in plant cover was slightly higher than the difference between subsequent cover classes on the scale used (5%), ranging between 10 and 15%. On the other hand, the results suggest that if total plant cover is < 60%, estimates at small scales are unreliable. This could be partly caused by the fact that a small change from the exactly vertical projection to an inclined one may markedly change the perception of plant cover because in the smallest plots plant height considerably exceeded plot diameter.

Cover of individual species

Individual plant species are potentially even more sensitive to subjectivity in cover estimates than total plant cover. Kent & Coker (1992) suggested that species which are in flower, attractive and conspicuous will tend to be over estimated in contrast to inconspicuous sterile plants. I was not able to test these assumptions because most plants were sterile. On the other hand, the results presented in Table 1 suggest that cover of both conspicuous (broad-leaved) and inconspicuous (narrow-leaved) plants included more often extreme cover estimates than those of intermediate plants. This indicates that observers had problems with estimates of plant cover in both groups.

The CV of plant cover estimates by individual observers was higher for group mean cover estimates < 5% than for higher values of plant cover, especially at larger scales. Thus, small differences in plant cover near the bottom of the cover scale were detected often inconsistently by the five observers. Similar results were reported by Tonteri (1990) for herbs in a boreal forest. However, if errors are expressed in absolute values, they are smaller for lower group means, in accordance with the common believe that smaller differences in plant cover can be more reliably estimated if the plant cover of a given species is small (Kent & Coker 1992; Dierschke 1994).

At medium mean cover (> 10%) the mean CV was close to 50%, independent of plot size. The careful selection of observers who took part in the experiment and their experience with this kind of work suggest that the relatively serious errors reported here could hardly be reduced in species-rich grasslands. In the studied plots sterile plants prevailed and numerous plants had similar shapes and colours of leaves. So, it was relatively difficult to make estimates of plant cover there, even if relatively small plots were used. In comparison with year to year variation in estimates of plant cover based on point quadrat data (expressed as frequency of hits) in an undisturbed species-rich grassland (e.g. Stampfli 1995), the variation in cover estimates among individual observers reported here was for many species much larger. This finding contrasts with a common belief (and hope) that problems of subjectivity of plant cover estimates have been over emphasized (Kent & Coker 1992).

Lepš & Hadincová (1992) compared plant cover estimated by two observers using the Braun-Blanquet 7-grade cover scale in species-poor wet meadows (18.6 species 25 m^{-2}). They found that in 57.5% of all cases the same cover class was estimated, in 39.5% the difference between observers was one cover class and in 3% more than one cover-class. I transformed my percentage cover data to the Braun-Blanquet cover scale with the aim of comparing all possible pairs of observers in the same way as Lepš & Hadincová (1992) did. The results were scale dependent, with the lowest discrepancy occurring at the largest plots, where the same cover class was estimated in 50% of the species. In 46% of the cases the estimates differed by one cover class and in 4% more than one cover class. However, in small plots the percentage of species with cover estimates differing by two cover classes or more increased to 40%. Only in ca. 20% of species was the cover estimate the same. The results presented for the largest scale correspond quite well to the results by Lepš & Hadincová (1992), even though their plots were much larger than mine. This comparison suggests that we can expect a similar magnitude of variation in plant cover estimates in grasslands with different species richness.

Some authors strongly recommend the use of frequency instead of subjective estimates of plant cover. According to Lawesson (2000) plant frequency can also be relatively easily estimated and is less sensitive to subjective errors. However, this type of data may suffer from errors caused by a failure to find and/or correctly identify all plant individuals occurring in the numerous subplots. As was recently shown, plant censuses made by experts include errors of 10-20% in grasslands, in small plots errors are even greater (Klimeš et al. 2001). Thus, frequency data based on plant censuses in numerous subplots may suffer from errors that are not necessarily smaller than those based on visual plant cover estimates.

The question of whether subjective plant cover estimates should be abandoned and replaced by quantitative methods cannot be unequivocally answered. The advantage of quantitative measurements is that most errors are systematic. This means that measured values are biased in the same direction and to the same extent. I found that this does not hold for visual plant cover estimates, even if the observers were intensively trained before the experiment. On the other hand, it seems that the hardly predictable errors of plant cover estimates can be minimized if several observers work together and compare their estimates. If three persons are involved, the work is slowed down by a factor of two to three which is still acceptable in many cases. Therefore, I suggest that if a non-destructive approach is required, such as in permanent plots, if the plots are relatively large (several m^2 or more) and the plant canopy is more or less closed, estimation of plant cover by eye may be the most efficient approach. Its accuracy can be improved if three observers co-operate and are working together in all experimental plots.

Acknowledgements. This work was financially supported by grants nos. 206/97/0937 and 206/01/1037 of the Grant Agency of the Czech Republic. I wish to thank Martin Dančák, Michal Hájek, Ivana Jongepierová and Tomáš Kučera who participated in the experiment. Jan Wim Jongepier is acknowledged for useful comments on the draft of the manuscript and for linguistic help. Finally I thank the anonymous referees and Jan Lepš for constructive comments which improved the manuscript.

References

Bråkenhielm, S. & Liu, Q. 1995. Comparison of field methods in vegetation monitoring. *Water Air Soil Pollut*. 79: 75-87.

Daubenmire, R.F. 1959. A canopy coverage method of vegetation analysis. *Northwest Sci*. 33: 43-64.

Dierschke, H. 1994. *Pflanzensoziologie*. Ulmer, Stuttgart, DE.

Dietz, H. & Steinlein, T. 1996. Determination of plant species cover by means of image analysis. *J. Veg. Sci*. 7: 131-136.

Everson, T.M., Clarke, G.P.Y. & Everson, C.S. 1990. Precision in monitoring plant species composition in montane grasslands. *Vegetatio* 88: 135-141.

Floyd, D.A. & Anderson, J.E. 1987. A comparison of three methods for estimating plant cover. *J. Ecol*. 75: 221-228.

Greig-Smith, P. 1983. *Quantitative plant ecology*. Blackwell, Oxford, UK.

Hanley, T.A. 1978. A comparison of the line interception and quadrat estimation methods of determining shrub canopy coverage. *J. Range Manage*. 31: 60-62.

Hope-Simpson, J.F. 1940. On the errors in the ordinary use of subjective frequency estimations in grassland. *J. Ecol*. 28: 193-209.

Kennedy, K.A. & Addison, P.A. 1987. Some considerations for the use of visual estimates of plant cover in biomonitoring. *J. Ecol*. 75: 151-157.

Kent, M. & Coker, P. 1992. *Vegetation description and analysis*. CRC Press, Boca Raton, FL, US.

Kershaw, K.A. 1973. *Quantitative and dynamic ecology*. Arnold, London, UK.

Klimeš, L. 1999. Small-scale plant mobility in a species-rich grassland. *J. Veg. Sci*. 10: 209-218.

Klimeš, L., Dančák, M., Hájek, M., Jongepierová, I. & Kučera, T. 2001. Scale-dependent biases in species counts in a grassland. *J. Veg. Sci*. 12: 699-704.

Lawesson, J.E. 2000. *A concept for vegetation studies and monitoring in the Nordic countries*. Nordic Council, Copenhagen, DK.

Lepš, J. & Hadincová, V. 1992. How reliable are our vegetation analyses? *J. Veg. Sci*. 3: 119–124.

Liu, Q.H. & Bråkenhielm, S. 1996. Variability of plant species diversity in Swedish natural forests and its relation to atmospheric deposition. *Vegetatio* 125: 63-72.

Marhold, K. & Hindák, F. (eds.) 1998. *Zoznam nižších a vyšších rastlín Slovenska* [*Checklist of non-vascular and vascular plants of Slovakia*]. Veda, Bratislava, SK. (In Slovak.)

Mueller-Dombois, D. & Ellenberg, H. 1974. *Aims and methods of vegetation ecology*. Wiley & Sons. New York, NY, US.

Röttgermann, M., Steinlein, T., Beyschlag, W. & Dietz, H. 2000. Linear relationships between aboveground biomass and plant cover in low open herbaceous vegetation. *J. Veg. Sci*. 11: 145-148.

Smartt, P.F.M., Meacock, S.E. & Lambert, J.M. 1974. Investigations into the properties of quantitative vegetational data. I. Pilot study. *J. Ecol*. 62: 735-759.

Smartt, P.F.M., Meacock, S.E. & Lambert, J.M. 1976. Investigations into the properties of quantitative vegetational data. II. Further data type comparisons. *J. Ecol*. 64: 41-77.

Smith, A. 1944. A study of the reliability of range vegetation estimates. *Ecology* 25: 441-448.

Stampfli, A. 1991. Accurate determination of vegetational change in meadows by successive point quadrat analysis. *Vegetatio* 96: 185-194.

Stampfli, A. 1995. Species composition and standing crop variation in an unfertilized meadow and its relationship to climatic variability during six years. *Folia Geobot. Phytotax*. 30: 117-130.

Sykes, J.M., Horrill, A.D. & Mountford, M.D. 1983. Use of visual cover assessments as quantitative estimators of some British woodland taxa. *J. Ecol*. 71: 437-450.

Symstad, A.J. 2000. A test of the effects of functional group richness and composition on grassland invasibility. *Ecology* 81: 99-109.

Tilman, D. 1999. The ecological consequences of changes in biodiversity: A search for general principles. *Ecology* 80: 1455-1474.

Tonteri, T. 1990. Inter-observer variation in forest vegetation cover assessments. *Silva Fennica* 24: 189-196.

Vanha-Majamaa, I., Salemaa, M., Tuominen, S. & Mikkola, K. 2000. Digitized photographs in vegetation analysis – a comparison of cover estimates. *Appl. Veg. Sci*. 3: 89-94.

van Hees, W.W.S. & Mead, B.R.. 2000. Ocular estimates of understory vegetation structure in a closed *Picea glauca*/ *Betula papyrifera* forest. *J. Veg. Sci*. 11: 195-200.

Westhoff, V. & van der Maarel, E. 1973. The Braun-Blanquet approach. In: Whittaker, R.H. (ed.) *Ordination and classification of vegetation*, pp. 617-726. W. Junk, The Hague, NL.

Received 19 December 2002;
Revision received 27 February 2003;
Accepted 10 April 2003.
Coordinating Editor: J. Lepš.