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Use of paired plots and multivariate analysis for the determination of goat grazing preference

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Abstract. Goat grazing is examined as a possible tool for grassland management. In this paper, goat grazing preferences are described. The proportion of biomass of particular species eaten by a goat was estimated on the basis of comparison of paired quadrats. The control quadrats were clipped before grazing and their biomass was compared with the biomass in grazed quadrats. Estimates of the proportion consumed were calculated for frequent species; they were significantly different among species; the most preferred species was *Polygonum bistorta*, a species with broad, soft, nutritious leaves. The least grazed species were *Agrostis tenuis* and *Galium harcynicum*. Various indices of food selectivity (e.g. forage ratio, electivity index) were calculated and their behaviour was compared. Canonical Correspondence Analysis and Redundancy Analysis with appropriate covariates reflecting the block design of the experiment were used to evaluate overall changes in species composition and yielded results similar to those from the direct estimation of the proportion consumed.

Keywords: Constrained ordination; Food selectivity; Grassland management; Mountain meadow; *Polygonum bistorta*.

Abbreviations: CCA = Canonical Correspondence Analysis; RDA = Redundancy Analysis.

Nomenclature: Rothmaler (1976).

Introduction

Meadows are among the most species-rich communities in Central Europe. However, with the exception of meadows above the treeline, the vast majority are man-made habitats and their maintenance is crucially dependent on human interference. Generally, when abandoned, the meadows are subject to a natural succession towards either shrub and forest communities, or, in some cases, to meadows in which some competitively strong herbs prevail. Traditionally, there are two kinds of meadow management: mowing and grazing (Bakker 1987, 1989).

It has repeatedly been shown (e.g. Blažková 1991; Rejmánek & Rosén 1992) that cessation of meadow management often leads to a dramatic decrease in species diversity. The problem of continued meadow management arises particularly in those situations when the traditional management is not economically feasible any longer. If a meadow is left fallow, its species diversity decreases; modern intensive, economically oriented management leads also to a decrease of species diversity. The aim of many recent grassland studies is to propose a management regime which is economically feasible and also preserves species diversity; low-intensity grazing seems to be promising in some cases (Bakker 1989) whereas high intensity grazing or overgrazing often leads to destruction of grassland ecosystems (see e.g. Levin 1993). An understanding of underlying processes is crucial for successful management. Grazing by large vertebrates affects both species composition and morphology of particular species (Díaz et al. 1992). The vegetation is affected in several ways, of which direct biomass consumption is only one. Other important factors are trampling, creation of gaps, increased nutrients due to defecation and urination, and increased nutrient availability as a result of increased turnover of nutrients. Trampling, urination and defecation considerably increase micro-scale heterogeneity. In some cases, gaps in the turf are a very important regeneration niche for many species (Oesterheld & Sala 1990; Williams 1992). Unlike mowing, grazing is a highly selective process because most grazers discriminate between species. Species differ in their palatability and in their resistance to all of the above-mentioned factors. Some species are even believed to be influenced positively by grazing (McNaughton 1979). The estimation of the consumed portion of particular species facilitates the understanding of the overall grazing effect. It is well known that ungulates, including domestic goats, selectively graze vegetation. Brehm (1879-1890) noted that although goats consume 449 plant species, they prefer some species to others. The quantification of grazing selectivity is generally difficult, however, particularly in species-rich plant communities.

Esophageally-fistulated individuals are often used for the quantification of diet composition (van Dyne & Torell 1964). Samples of the forage consumed by animals in grazing experiments are directly collected and sorted by species. Unfortunately, it is expensive to obtain surgically prepared esophageally-fistulated individuals. Also, determination to the species level in consumed forage may be difficult or impossible, particularly in species-rich communities.

Our aim was to test a new method for estimation of goat grazing selectivity, based on comparison of species composition of grazed and ungrazed plots in a short-term grazing experiment and to compare various possibilities of data analysis from this experiment.

Methods

Study site

The study was performed in the Krušné hory Mts., W. Bohemia, Czech Republic, at the location of the former village Chaloupky (Neuhaus) near Nejdek. The study site is located at an elevation of 820 - 840 m a.s.l., in the upper part of the floodplain of the Rolava River and adjacent slopes. The meadows were established in the 15th and 16th centuries after clearance of the mountain forests. The meadows were left fallow ca. 40 yr ago and have not been mown since. With time, grass species usually become dominant in the abandoned meadows, mostly *Agrostis tenuis*, *Deschampsia cespitosa*, *Holcus mollis* and *Poa chaixii*; average species richness was about six to seven species per 0.5 m × 0.5 m quadrat.

Field experiment

The experiment was carried out in August 1992. The effect of grazing was studied using a series of six circular blocks of ca. 40 m^2 each. In each block, two 1-m^2 square plots were selected subjectively as the most homogeneous parts of a block. Each of the plots was divided into four subplots; two of them (on a diagonal) were clipped as a control before grazing (these plots are referred to as ungrazed) and the other two were clipped after grazing. After clipping, the living biomass from each quadrant was sorted to species. The standing dead and moss biomass were also determined. Each block was grazed by a tethered goat for two half-days within one week. The average biomass on the plot before grazing started was estimated to be 215 g/m^2 of dry mass. Although this does not lead to a high grazing pressure, the goat grazed throughout the whole block (note that the total food supply within the whole block was about 10 kg of dry mass).

Data analysis

Two types of data analysis were performed: first, the proportion of dry species biomass eaten was estimated for the total biomass and for each species in each plot, where the species was present in all the subplots and where its dry mass exceeded 2 g. Since the goat was never able to eliminate any species totally, we concluded that if the species is absent in any quadrant, the reliability of the estimate is too low to be included in the analysis. The same was concluded in the case that the total dry mass of a species in a 1-m^2 plot does not reach 2 g. As an estimate of the proportion eaten

$$1-\frac{\text{dry mass of a species in grazed subplots}}{\text{dry mass of a species in ungrazed subplots}} \qquad (1)$$

was used. This estimate is based on the assumption that the plant mass in grazed and ungrazed quadrats before the grazing started, was the same. For further analysis, only species where the estimates were available in at least three plots were used (eight species). One-way ANOVA was used to test the null hypothesis that the proportions of dry mass consumed were the same for all the species; the Student-Neuman-Keuls (SNK) test was used for multiple comparison (Zar 1984). Because ratios are difficult to treat statistically, and in a few cases the biomass in grazed quadrants (after grazing) was higher than in ungrazed ones, ANOVA was applied to values

$$1-\frac{\text{dry mass of a species in grazed subplots}}{\text{dry mass of a species in all subplots}} \qquad (2)$$

after angular transformation (Zar 1984).

Two estimates of the proportion of species biomass eaten were obtained: the first one was an average of proportions in particular plots (i.e. of all the plots, where the species was present in all the quadrants and where the biomass exceeded 2 g, see above); in the second one, equation (1) was applied to biomass values totalled over all the plots and the ratio was computed for the totals. In the first case, the estimate is equally influenced by all the plots used for calculation. The second estimate is influenced more by plots with a higher biomass of the species under consideration. Based on the second value, we calculated various measures of food selectivity: the forage ratio, electivity index, and indices Q and D of Jacobs (1974). Discussion of various indices is given by Cock (1978). Forage ratio (FR, method 2 of Cock 1978) is defined as the ratio of the fraction of a species in the feeders ratio to the fraction of the same species in the environment. The forage ratio can also be calculated as the ratio of proportion of species consumed to the proportion of all the vegetation consumed. The *FR* varies from 0 to 1 for avoided species and from 1 to ∞ for preferred species; electivity index (*E*, method 5 of Cock 1978) is a simple transformation of *FR*, varying from –1 to 1, negative for avoidance, positive for preference

$$E = \frac{FR - 1}{FR + 1} \quad (3)$$

The index Q (method 4 of Cock 1978) is defined:

$$Q = \frac{\text{amount of species eaten/amount of rest eaten}}{\text{amount of species in environment/ amount of rest in environment}} . \quad (4)$$

Originally, the index was defined for two prey types: for our purposes all other than focal species are pooled into ‘prey type II’ (Cock 1978). The value of the index varies from 0 to 1 for food avoidance, and from 1 to ∞ for food preference. With the transformation analogous to equation (3), index *D* is obtained

$$D = \frac{Q - 1}{Q + 1} \quad (5)$$

ranging from –1 to 1 (method 8 of Cock 1978).

The second analysis was based on constrained ordinations, using the CANOCO program (ter Braak 1987; Jongman et al. 1987; version 3.1), which enables a better hypothesis testing, corresponding to the design of the experiment. Because a randomized complete block design was used in the experiment, the number of the quadrat was used as a covariable (categorical, coded as several dummy variables) and the ‘grazing/non-grazing’ as the only explaining variable. Two types of analysis were used: (1) Redundancy Analysis (RDA), both without standardization to reveal the overall grazing effect, and with standardization by sample norm, and (2) Canonical Correspondence Analysis, in order to show grazing preferences. See Jongman et al. (1987) for further information on the use of constrained ordinations for analysis of ecological experiments.

Results

The average biomass was 215.8 ± 29.6 g/m^2 (dry mass, mean ± standard error) in ungrazed plots and 157.4 ± 20.9 g/m^2 in grazed plots. From this we could estimate that ca. 27.1 % of the biomass was consumed by a goat. The average estimate for a particular plot was 25.6 ± 3.4 % (mean ± S.E.). The diversity of grazed and ungrazed plots did not differ significantly and the proportion of biomass consumed was not correlated with plot diversity. Analysis of variance revealed significant differences (P = 0.021) in goat grazing preference among the eight common species (Table 1). Multiple comparisons (SNK-test, $\alpha = 0.05$) showed significant differences between the species which was grazed most, *Polygonum bistorta*, and the two least grazed species, *Galium harcynicum* and *Agrostis tenuis*. The other species have an intermediate position (Table 1). Results of all the indices used are similar.

The non-standardized RDA runs revealed significant differences between grazed and ungrazed plots (P «

Table 1. Biomass estimations for eight common, widely dispersed species before grazing (g/m^2 dry weight), and percentage of grazed species biomass, estimated as an average of percentages in particular plots (Cons. Avg. %). Statistical differences determined by SNK-test: species labelled with the same letter do not differ significantly at α = 0.05. Also shown are the species scores on the first canonical axis (the higher the value, the less the species is consumed), the estimates of percentage grazed based on the totals for all the plots (Cons. Tot. %), forage ratio (*FR*), and values of indices *E*, *Q*, and *D* (see text for description of indices).

Species	Biomass	Cons. Avg.%	Difference	CCA	Cons. Tot.%	*FR*	*E*	*Q*	*D*
Polygonum bistorta	1.4	70	a	– 4.7	79	2.97	0.50	10.51	0.83
Festuca rubra	7.4	45	ab	– 0.3	51	1.90	0.31	2.84	0.47
Poa pratensis	15.2	36	ab	– 0.3	26	0.96	– 0.02	0.97	0.02
Holcus mollis	36.3	36	ab	– 1.2	47	1.78	0.28	2.51	0.42
Poa chaixii	37.3	32	ab	– 0.3	33	1.26	0.11	1.39	0.16
Achillea millefolium	8.4	26	ab	0.0	19	0.74	– 0.14	0.69	– 0.19
Galium harcynicum	31.7	17	b	1.2	12	0.45	– 0.38	0.38	– 0.45
Agrostis tenuis	41.0	13	b	0.7	12	0.46	– 0.37	0.38	– 0.45

Species appearing in the plots, but not used in the analyses (because they were either highly clumped or had a low biomass): *Alchemilla* sp., *Calamagrostis villosa*, *Campanula rotundifolia*, *Carex leporina*, *Deschampsia cespitosa*, *D. flexuosa*, *Festuca rubra*, *Juncus filiformis*, *Luzula multiflora*, *L. pilosa*, *Nardus stricta*, *Potentilla erecta*, *Ranunculus repens*, *Rumex acetosella*, *Stellaria graminea*, *Trifolium repens*, *Veronica chamaedrys*, *Viola palustris*, *V. saxatilis*.

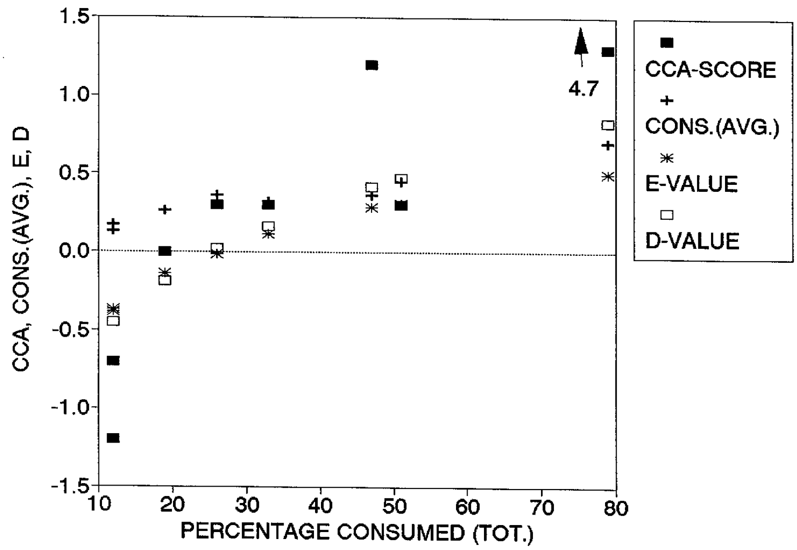

Fig. 1. Relationship between percentage of species biomass consumed, as estimated from biomass totals for all the plots and other characteristics of species preference: CCA - species CCA score (the axis orientation is changed to achieve the highest values for the most consumed species); CONS.(AVG.) - the estimate of percentage consumed estimated as an average of the percentages consumed in particular plots and expressed as a number between 0 and 1; E-VALUE - electivity index *E* (Eq. 3); and *D*-VALUE - index *D* (Eq. 5).

0.01). However, this reveals only that the amount of dry mass in grazed and ungrazed quadrants was different for at least some species. Neither the standardized RDA, nor the CCA provided significant results, indicating no significant species preferences. Clearly, the multivariate test is weaker than that provided by ANOVA, as it includes a high amount of 'noise': i.e. a high proportion of quadrats where a species was rare or absent. Nevertheless, the score on the first CCA axis (i.e. the constrained axis, constructed to provide the best fit to the grazed-ungrazed dichotomy) conforms to the grazing preference determined by direct estimates of percentage grazed (Table 1). Unlike the direct estimates, the CCA score also reflects the intra-block comparisons - i.e. the amounts of biomass of the species grazed as compared with other species in the same block.

Discussion

Goats have been domesticated worldwide, including areas with harsh environmental conditions. Studies in various parts of the world have shown their grazing selectivity (Malechek & Leinweber 1972; Provenza & Malechek 1984; Schacht & Malechek 1990). It is known that goat browsing results in changes of plant species composition; some species decline, whereas those avoided by goats increase (Riggs & Urness 1989). Indeed, goat grazing was considered as a management tool to change deer diet in winter (Riggs et al. 1990). In Bohemia, goats were used to prevent spreading of invasive shrubs in protected areas of dry grassland (Kohout & Zvoníček 1989).

The selectivity of animal grazing may operate at several levels (Crawley 1983): habitat selection, preference for particular species within a habitat and preference for a particular part of the plant. Our experiment was designed only to test for within-habitat preferences. Both the direct estimates of percentage of dry mass consumed and the ordering of species in CCA correspond well with our non-quantitative observations of goat behaviour, particularly the preference for broad soft leaves of *Polygonum bistorta* and of the grass *Holcus mollis*. The leaves of *Polygonum bistorta* are not only soft, but also very nutritious (see Ketnerová 1991). Since *Polygonum bistorta* is known to attain a high dominance on some abandoned mountain meadows, goat grazing could be used as a measure to suppress this species. Similarly, *Holcus mollis* is known to be preferred forage (Grime et al. 1988).

The use of various indices of grazing preference gave very similar results (Table 1, Fig. 1). Index *E* is just a transformation of the forage ratio and *D* is a transformation of index *Q*; the original and transformed values provided the same information, differing only in the scale used. Nevertheless, in our data the differences between *D* and *E* are also negligible. On the other hand, some differences were found between various ways of estimating the proportion consumed. The theoretical arguments for the use of index *Q* or *D* are correct; nevertheless, in studies like this one, the results of *Q* or *D* are nearly the same as when the forage ratio or index *E* are used. In similar studies, the main difficulty lies in estimating the consumption of different species foraged, and also in estimating the species composition of the vegetation, particularly because of the high spatial variability of vegetation. Besides this variability of vegetation before the experiment, some variability occurs because of goat behaviour: the plots are grazed more near the margins than near the centre of the circle. Goats usually avoid grazing in areas with faeces and resting places.

The time interval between clipping of the control plots and the grazed plots was always shorter than one week; each block was grazed twice, and it was necessary to have some interval between the two grazing occasions. Nevertheless, as the experiment was done in late August, the biomass change with time was negligible in unclipped plots. It is unlikely that the small time difference could influence the results; however, on control plots clipped to the ground, some species did regenerate quickly after clipping. To get more significant differences in multiple comparisons and to achieve statistical significance in multivariate methods, more plots are needed; with the present sample size, the power of the test is low, because the selectivity is not very pronounced and the material is extremely variable.

The use of esophageally-fistulated individuals (Van Dyne & Torell 1964) seems to overcome some of these problems. Besides being expensive, this method also has its own limitations. Particularly, there is a bias, that could be caused by incomplete sample recovery, but there are methods to overcome this problem (Barth & Kazzal 1971). Nevertheless, the inability to identify plant fragments remains a serious problem for identifying infrequent species. It was shown that the correspondence between the percentage of particles and the proportion of weight is reasonably good; nevertheless, microscopic determination is usually difficult and not always successful, even on a functional group level (Van Dyne & Torell 1964). For vegetation studies, the interest is in identification of all the species, not just a group. The majority of studies with esophageally-fistulated individuals concentrate on forage quality, where the problem of determination of rare species is not important. Most studies do distinguish forbs, grasses, sometimes shrubs, and a few quantify the most important species. This method does not solve the problem of spatial heterogeneity of vegetation, because it is always necessary to select random samples of vegetation for comparison. The use of paired plots enables partial control over plot heterogeneity. Further, it is not clear, how the grazing habits of a goat might be changed by the stress imposed by the fistula. Our method would be far less laborious in species-poor vegetation. However, what is of ecological interest and what might have some consequences for nature conservation practice, is the selectivity in natural species-rich communities.

The main advantage of the paired quadrat method lies in the fact that the estimation of food supply and food consumed is made by the same method and that the paired plots (as in any block experimental design) allows some control over spatial heterogeneity. The use of paired plots will be useful in experiments where animals are allowed to move freely through a certain area. At this scale, the paired plots would also test for the habitat preference and the selection of species within a habitat. The main disadvantage of the method is its dependence on the assumption that the species biomass in grazed and ungrazed quadrants of the quadrat before grazing started was the same. There is a possibility of reducing the error introduced by violation of this assumption in further studies: an attempt should be made to estimate the biomass prior to the grazing in all the plots by some non-destructive method (e.g. the canopy intercept method, Frank & McNaughton (1990), or just a visual estimation) and then calibrate this estimate by analysis of control plots clipped immediately after the non-destructive estimation (see Pielou (1981) for statistics connected with the calibration). However, the point intercept method is relatively imprecise for rare and scattered species. So, whether this approach really reduces the error remains to be seen.

The relationship between herbivory and plant species diversity may be complicated; it often depends on the palatability of particular species and the relationship between palatability and competitive ability (Pacala & Crawley 1992). Nature conservation is usually more interested in some species than in others. The knowledge of grazing preference is only one piece of information needed for management planning. Nevertheless, as reported by Kettnerová (1991), it seems that goat grazing may be a useful measure in areas where *Polygonum bistorta* has achieved a high degree of dominance in previously species-rich meadows.

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