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RESEARCH NOTE

Predicting the species richness of Alpine pastures using indicator species

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Summary

1 Plant species richness is often used as a criterion in the assessment of ecological quality. Complete species inventories are time-consuming to establish, and the resulting information may be more detailed than needed. In this study we investigated how reliably species richness on Alpine pastures can be estimated from the presence or absence of a limited number of indicator species.

2 Based on data from a vegetation survey in 200 plots (1 m^2) on ten Alpine pastures in Glarus (northern Swiss Alps), we identified 36 vascular plant species that were significantly more frequent in species-rich than in species-poor plots. The number of these 'richness indicators' in a relevé increased linearly with actual plant species richness ($r^2 = 0.80$) but was only weakly related to the number of non-indicator plant species ($r^2 = 0.10$).

3 If subsets of 3, 5, 8, 10 or 20 species are randomly drawn from the 36 'richness indicators', the precision of species richness estimates increases with increasing subset size and with increasing frequency of the species in the subset. For the most species-rich relevés, the precision of species richness estimates is already close to maximum with subsets of eight species.

4 Character species from species-rich Alpine pastures at regional scale (phytosociological classification) are found to be less effective in predicting species richness than our locally defined set of 'richness indicators'.

5 Pasture areas with high species richness ($\geq$ 25 plant species m^{-2}) can be roughly identified from the presence of at least half of the species in a given indicator species set (which should consist of at least eight species). This information can be used for a rapid mapping of the most species-rich parts within Alpine pastures.

Keywords: Alpine pastures, indicator species, species richness, vegetation mapping

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Introduction

Species richness is one of the components of biodiversity and is often used as criterion in ecological assessments (Longino & Colwell 1997; Mac Nally & Fleishman 2002). Alpine pastures include a significant fraction of the plant species pool of Alpine regions (Bätzing

1991; Müller *et al.* 2003), and well-managed pastures can support species-rich plant communities of high conservation value (Spatz 1975; AGFF 1990). In the last decade, species richness of Alpine pastures became an important aspect in the search for ecological quality and sustainable forms of land use (Spatz & Papachristou 1999; Müller 2002). To account for species richness in land use planning, it first needs to be assessed. Given the large areas covered by alpine pastures, an efficient assessment method is essential. Exhaustive species inventories are time-consuming to establish and require specialized botanical knowledge, while the resulting information may be more detailed than needed for planning. A possible alternative is the estimation of species richness from the presence or absence of only a few indicator species (Noss 1990; Fleishman & Murry 2000; Mac Nally & Fleishman 2002).

The indicator species approach has been used successfully to evaluate ecological quality in agricultural areas and to map meadow vegetation in the Swiss lowlands (Dietl *et al.* 1981; Eggenberg & Hedinger 1997). These studies were based on the assumption that the vegetation can be subdivided into distinct communities with relatively homogeneous species composition, each of which occurs under certain site conditions and presents a characteristic species richness. Accordingly, the character species of these plant communities (according to the phytosociological classification) could also be used for a rough assessment of species richness. However, such an approach might not be feasible on Alpine pastures because of their heterogeneous site conditions and the multitude of factors influencing the composition of the vegetation at various spatial scales (Müller 2002). For example, small-scale vegetation patterns on pastures are strongly related to dung distribution and local grazing intensity, whereas these factors do not determine large-scale vegetation patterns (Erzinger 1996; Jewell 2002). Also, some character species of plant communities are rare in intensively grazed Alpine areas, while on the other hand, species that are characteristic of different plant communities in the lowlands may co-occur at higher elevation. As a result, character species of the phytosociological classification that provide a good indication on the species richness in the lowlands may fail to do so on Alpine pastures.

In this study we investigate whether the indicator species approach can still be used to estimate species richness on Alpine pastures. To this end we use data from a vegetation survey on pastures in the northern Alps (Müller *et al.* 2003) and model the plant species richness of 200 plots (1 m^2) as a function of the number of indicator species recorded in the plots. We repeat these calculations with various sets of indicator species that differ in the number of species included and in the way these species are selected to answer the following questions:

1. How precisely can the species richness of Alpine pastures be estimated using the indicator species approach?
2. Does the precision depend on the number of species used as indicators?
3. Can species richness be predicted from indicator species defined at regional, rather than local scale?
4. Can we identify a particularly species-rich pasture (≥ 25 vascular plant species per m^2) using the indicator species approach?

Methods

Our data set consists of 200 vegetation relevés in 1-m^2 plots distributed over ten Alpine farms in the canton of Glarus, which is part of the north-eastern Swiss Alps (47° N, 9° E).

***Table 1.** "Species richness indicators" for Alpine pastures, i.e. plant species that are significantly more frequent in species-rich than in species-poor relevés (*P < 0.01; *Müller* et al. *2003). Species are ordered by the* Chi^2*-values of logistic regressions relating their occurrence to the number of species per 1-*m^2 *plot; high* Chi^2*-values indicate a good regression fit. Ecological indicator values from Landolt (1977), ranging from 1 (= low) to 5 (= high) are given for soil moisture (F), soil pH (R), and soil nutrients (N).*

Indicator plant species	Chi^2	F	R	N
Lotus corniculatus ssp. *alpestris*	65.47	2	4	3
Prunella vulgaris	57.58	3	3	3
Rhinanthus alectorolophus	52.29	3	4	3
Leucanthemum vulgare	33.75	2	3	3
Sesleria caerulea	31.99	2	5	2
Trifolium pratense	31.18	3	3	3
Cirsium spinosissimum	30.07	4	3	3
Polygonum viviparum	29.17	2	4	2
Festuca violacea	28.98	3	2	3
Polygala alpestris	28.10	2	4	2
Thymus serpyllum	22.09	1	3	2
Leontodon hispidus	20.00	3	3	3
Plantago lanceolata	19.75	2	3	3
Luzula sudetica	17.94	3	2	2
Potentilla erecta	16.46	3	–	2
Galium anisophyllon	13.68	2	3	2
Anthyllis vulneraria ssp. *alpina*	13.64	1	3	2
Crepis aurea	13.3	3	3	4
Briza media	13.14	2	3	2
Trifolium thalii	12.43	3	4	3
Helianthemum nummularium	12.21	1	4	2
Luzula multiflora	11.74	3	2	2
Homogyne alpina	11.26	3	3	2
Hieracium murorum	11.03	2	3	3
Trifolium badium	11.03	3	4	3
Euphorbia cyparissias	10.85	2	3	2
Poa alpina	10.00	3	3	4
Campanula barbata	9.96	3	2	2
Carex pilulifera	9.95	3	2	3
Euphrasia minima	9.30	3	2	2
Luzula luzuloides	9.08	2	2	2
Gentiana ciliata	7.67	3	4	2
Vaccinium uliginosum ssp. *gaultherioides*	7.43	5	1	2
Dactylorhiza maculata	6.90	4	2	2
Phleum alpinum ssp. *rhaeticum*	6.85	3	3	4
Vaccinium myrtillus	6.70	3	1	2

The plots were distributed according to a systematic stratified design so as to be representative of the Alpine pasture area of this region. The pastures are grazed by cattle between 15 June and 30 September. The physical setting and land use of the farms has been described by Müller (2002). The vegetation survey took place in June-August 2000. The cover of all vascular plant species was recorded using the scale of Dietl (1985) and the nomenclature of Lauber & Wagner (1998). A detailed analysis of plant species richness in relation to management and soil chemistry is presented by Müller *et al.* (2003).

To select indicator species using purely numerical criteria, the relationship between plant species richness and the occurrence of individual species was analysed for the 87 plant species (out of 164) that were present in at least 5% of all relevés. Logistic regression was used to test if each species' occurrence was significantly related to the species richness of the plots. These tests revealed 36 plant species that are more frequent in species-rich than in species-poor pasture parts within the study area (Table 1). Relationships between the number of these indicators in each relevé and its actual plant species richness as well as the number of other species were analysed with linear regression using the statistical package JMP 3.2.2 (SAS Institute INC, Carey, NC, USA).

To assess how accurately species richness can be estimated from a limited number of indicator species, ten replicate subsets of $n=$ 3, 5, 8, 10 or 20 species, respectively, were randomly drawn from the 36 previously selected species. In the following the index $k=$ 1, 2... 10 will identify the individual subsets with same n. For each of the 50 subsets (defined by n and k), the 200 relevé plots were subdivided into $n+1$ classes of plots containing $i = 0, 1, 2... n$ indicator species. For each class (defined by n, k and i) we calculated the mean species richness of the plots included in the class (s_{nki} = predicted species richness) and the standard deviation (SD_{nki} = imprecision of the prediction). We then assessed the overall accuracy of estimation obtained with a subset size n by considering (a) the variability of predicted species richness among the ten replicate subsets (SD of the ten values of s_{nki} for a given n and i) and (b) the mean imprecision of the prediction (mean of the ten SD_{nki} for a given n and i).

We further examined how accurately plant species richness can be predicted from the presence or absence of indicator species defined at regional scale. To this end we used a set of eight species that were considered character species of species-rich Alpine pastures in the north-eastern Swiss Alps in the phytosociological classification of Dietl (1985). These species are *Crepis aurea, Festuca violacea, Helianthemum nummularium, Leontodon hispidus, Trifolium badium, Trifolium pratense, Plantago lanceolata,* and *Lotus corniculatus.* We calculated predicted species richness and the imprecision of the prediction in relation to the number of indicator species present in the same way as described above.

Results and discussion

SPECIES RICHNESS IN RELATION TO THE NUMBER OF INDICATOR SPECIES

The 200 vegetation relevés contain between 0 and 19 of the 36 'richness indicator species' (Fig. 1, cf. Table 1). The number of indicators is linearly related to the total number of plant species per relevé ($r^2 = 0.80$, Fig. 1a). This strong association mainly reflects the fact that the number of non-indicator species varies over a smaller range (from 5 to 14) than the number of indicator species (Fig. 1b); indeed, there is only a weak (yet significant) positive relationship between the number of indicator species and the number of non-indicator species ($r^2 = 0.10$). Thus, if the 36 richness indicators do (statistically) 'predict' species richness, this is because variation in their number determines the variability of species richness across our data set, and not because their presence indicates site conditions under which many non-indicator species can occur as well.

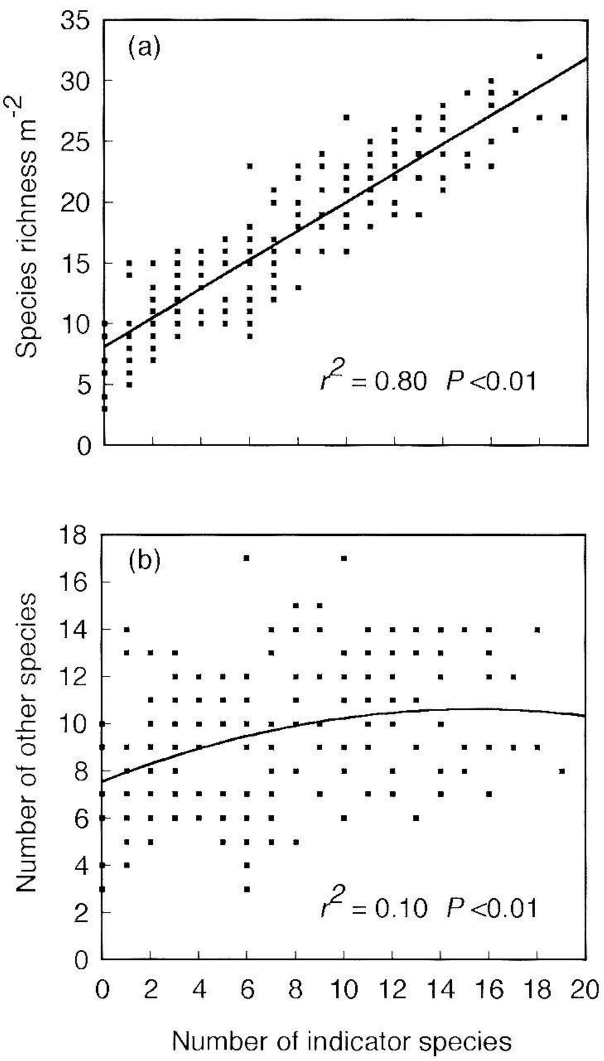

Fig. 1. *Relationships between the number of indicator species (out of a total of 36) recorded in a vegetation relevé (1m²) and (a) the total number of plant species in the relevé (species richness) and (b) the number of other (non-indicator) species. Data are from 200 vegetation relevés in 1-m² quadrats on Alpine pastures in the Northern Swiss Alps (Müller* et al. *2003). Symbols show data from individual relevés, and regression lines (linear or quadratic) show the mean ('predicted') species richness in relation to the number of indicator species.*

This result is probably due to the large number of indicator species included in the analysis (almost 50% of the frequent species) and to the complexity of vegetation gradients on Alpine pastures. In areas where one environmental gradient determines the variation in plant species composition and species richness, any species whose frequency is related to this environmental gradient would be a good indicator of species richness. These conditions are fulfilled on our Alpine pastures for particularly species-poor areas: the latter occur in either extremely enriched or extremely impoverished areas, and accordingly, they are well indicated by five plant species associated with these conditions (*Rumex alpinus, Poa supina, Senecio alpinus, Phleum pratense, Ranunculus acris;* Müller *et al.* 2003). In contrast, species-rich areas on Alpine pastures can be found under a wide range of site conditions. This heterogeneity is particularly pronounced in our study area given the occurrence of several bedrock types, which cause rather different local soil conditions promoting different plant communities (Marti *et al.* 1997; Oberholzer 1942). Not surprisingly, species richness in these various communities can be associated with different plant species.

The problems related to heterogeneous site conditions could be reduced by subdividing the Alpine pasture area into strata with similar site conditions and defining a smaller set of richness indicators for each stratum. However, this procedure, while reducing the number of species to consider in each stratum, would be complicated to apply and would still require a broad local species knowledge. To make the mapping of species richness feasible even for inexperienced observers, the number of indicator species to consider needs to be strongly reduced (Conroy & Noon 1999).

When subsets of 3, 5, 10 or 20 randomly selected species are used as richness indicators, the average species richness still increases linearly with increasing number of indicators present (Fig. 2). The relationship between species richness and number of indicators depends on the size of the indicator species subset: the smaller the subset, the higher the average species richness of a relevé in relation to the number of indicators present (Fig. 2a). For example, relevés including two indicators out of a 10-species subset containes on average four species more than relevés with two indicators out of a 20-species subset. If the fraction of indicator species present, rather than their absolute number, is used as indicator variable, this effect disappears (Fig 2b), yet the shape of the relationship still depends on subset size: linear relationship for subsets of up to five species and saturating relationship for larger subsets.

PRECISION OF SPECIES RICHNESS ESTIMATES

The variation in predicted species richness among replicate subsets of same size ranges from 0.9 to 2.07 and is unrelated to subset size (Table 2a). This variation reflects the differing degree of association of the 36 species from which subsets have been drawn with species-rich relevés (cf. Chi^2-values in Table 1). It indicates the bias in predicted species richness that is likely to result when a few indicator species are arbitrarily selected out of a larger set, for example species that are familiar to the observers or that flower at the date of survey. Compared to the range of predicted values (from 10 to 25), the bias is relatively small, meaning that the precise selection of a subset of indicators does not have a great importance for the estimation of species richness.

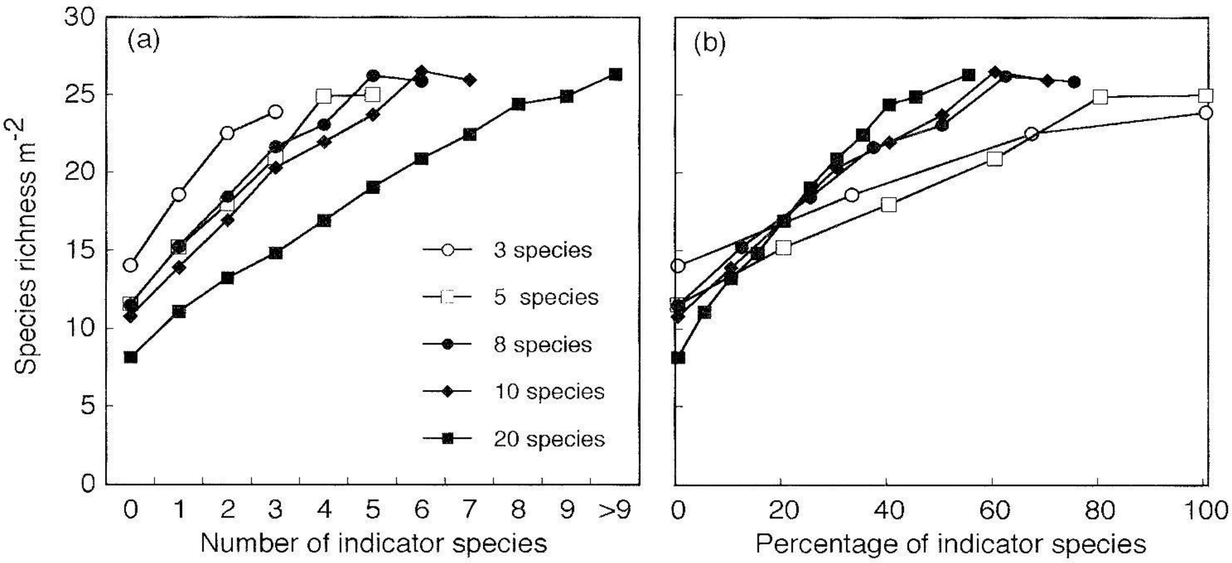

Fig. 2. Relationships between the mean ('predicted') plant species richness of a 1-m^2 quadrat on Alpine pastures and (a) the number or (b) the percentage of indicator species present in the quadrat, for subsets of indicator species of differing size. For each subset size, ten replicate subsets of indicators were randomly drawn from a total of 36 preselected indicator species (Table 1); means of these ten subsets are shown; for their variability see Table 2. Data source as in Fig. 1.

Table 2. Variability of species richness estimates based on the number of indicator species present in a vegetation relevé (1 m^2), for subsets of indicator species of different size that were randomly drawn from a total of 36 pre-selected indicator species. For each subset size and each number of indicator species present, the Table gives (a) the variability (standard deviation, SD*) of predicted species richness among the ten subsets, and (b) the variability of actual species richness among relevés (means of the* SD *calculated for each of the subsets). Greater variability indicates that species richness is estimated less precisely.*

Species present	Subset size (number of indicator species)				
	3	5	8	10	20
(a)	*SD* of predicted species richness among subsets				
0	1.06	1.58	1.26	0.98	0.48
1	1.28	2.07	1.14	1.54	0.57
2	2.29	1.37	1.48	1.53	0.63
3		3.24	1.34	1.61	0.58
4			2.84	1.31	1.22
5			0.89	1.58	0.71
6					0.84
7					1.06
8					1.32
> 8					1.57
mean	1.54	2.07	1.49	1.43	0.90
(b)	*SD* of actual species richness among relevés				
0	5.19	3.30	4.46	3.86	2.78
1	4.69	5.06	4.75	4.17	2.67
2	3.27	4.75	4.48	4.59	3.36
3		3.50	4.12	4.01	3.90
4			2.61	3.31	3.76
5			3.70	2.54	3.77
6					3.81
7					3.22
8					3.24
> 8					3.35
mean	4.38	4.15	4.02	3.75	3.39
mean ≥ 50%*	3.27	4.13	3.16	2.93	3.41

* Mean SD for estimates based on the presence of ≥ 50% of the species

The variation in actual species richness among relevés that include the same number of indicators (imprecision of estimation) decreases with subset size from a mean of 4.38 for 3-species subsets to a mean of 3.39 for 20-species subsets (Table 2b). The dependence of the imprecision of prediction on subset size is most pronounced when only few indicator species are present in a plot: in this case the estimation is very imprecise with the smaller subsets. When more than half of the indicator species are present in a relevé, the precision of species richness estimation differs little among subsets of 8, 10 or 20 species. Therefore, if the indicator species approach is used to identify particularly species-rich areas, the precision will be hardly improved by using more than eight species as indicators.

Not only predicted species richness varies among the ten replicate subsets of same size (Table 2a); the accuracy of species richness estimation also does. For example, among the ten 8-species subsets, the regression fit of species richness against number of indicators ranges from $r^2 = 0.2$ to $r^2 = 0.7$. This variation is related to the number of plots that include more than half of the species of a subset: the greater this number, the more precisely is species richness estimated by the number of indicator species (Fig. 3).

Table 3. *Variability (standard deviation) of actual species richness among relevés containing the same number of indicator species, for indicators defined at local scale (8-species subsets randomly drawn from our 36 local richness indicators) and at regional scale (character species of species-rich Alpine pastures in the phytosociological classification of Dietl 1985). Greater variability means that species richness is estimated less precisely.*

Species present	Local scale	Regional scale
0	4.46	3.72
1	4.75	4.30
2	4.48	4.55
3	4.12	4.99
4	2.61	4.67
5	3.70	3.97
6		5.72
7		
mean	4.02	4.56

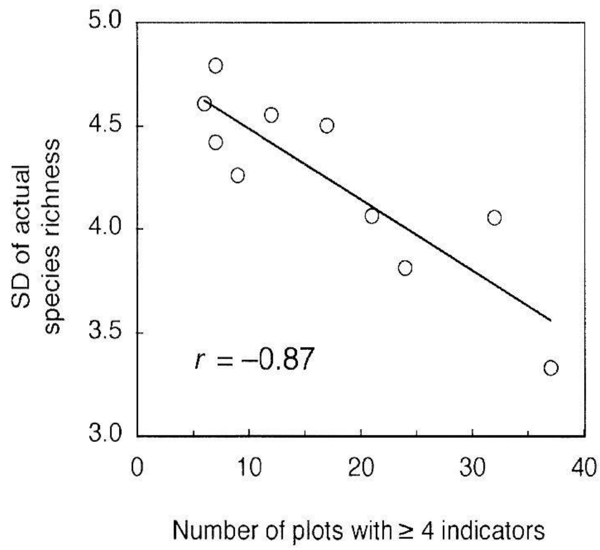

Fig. 3. *Relationship between the precision with which species richness can be estimated using a certain set of indicator species and the number of relevés containing at least 50% of these indicators, illustrated for ten different 8-species subsets randomly drawn from a total of 36 pre-selected indicator species (Table 1). Increasing precision is shown by a decreasing variation (standard deviation, SD) of actual species richness among plots with the same number of indicator species.*

PHYTOSOCIOLOGICAL CHARACTER SPECIES AS RICHNESS INDICATORS?

Methods to predict species richness that are based on a numerical selection of indicator species are currently considered more objective and more repeatable than methods based on expert knowledge (Conroy & Noon 1999). However, the latter may yield more accurate results as they are generally derived from extensive observational evidence. The phytosociological classification is a well-established expert knowledge-based system in Central Europe. The phytosociological system has so far been used as a basis to map species richness in more homogeneous vegetation types, such as dry meadows or forests (Eggenberg & Hedinger 1997; Walcher 1984).

In our study, species richness is predicted less accurately by indicator species selected at regional scale using phytosociological criteria (Dietl 1985) than by those selected randomly but at local scale (Fig. 4): relevés containing five or six indicator species out of the randomly selected 8-species subsets are on average substantially more species-rich than those containing five or six species from Dietl's (1985) set. Species richness estimates are also less precise with the regional set than with locally selected 8-species subsets (local scale; Table 3).

The set of species from Dietl (1985) was based on a classification system developed for the entire northern Swiss Alps instead of being based on the local patterns of species distribution of our farms (Müller *et al.* 2003). These local patterns may influence how the occurrence of particular species relates to species diversity. Accordingly, it is not surprising that a regional classification system is related to species diversity less closely than a local system. It suggests that our set of 36 indicator species would be less suitable to assess species richness on other farms than those investigated.

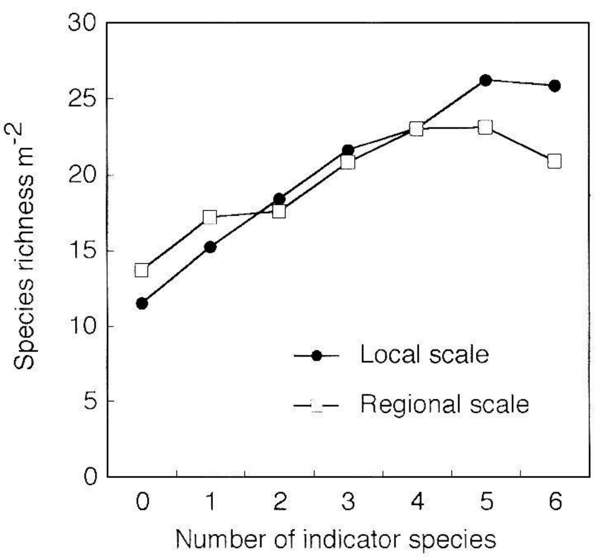

Fig. 4. Comparison of species richness estimates (cf. Fig. 2) obtained with a set of eight character species for species-rich Alpine pastures, defined at local scale (8-species subsets randomly drawn from our 36 local richness indicators) and at regional scale (character species of species-rich Alpine pastures in the phytosociological classification of Dietl 1985); for the precision of estimates see Table 3.

IDENTIFICATION OF SPECIES-RICH PASTURE AREAS

If particularly species-rich pasture areas are defined as those where species richness is more than 50% above average, this means for our data set that relevés should contain ≥ 25 species (mean of the 200 relevés = 16.6 species m^{-2}), a criterion fulfilled by 23 relevés. According to Fig. 2b, the presence of 25 species m^{-2} is predicted for relevés that contain ≥ 40–50% of the indicator species from subsets of ≥ 8 species. Chi-square tests done for each 8-species subset show that relevés which include at least four indicator species are significantly more likely to be particularly species-rich than the others (details not shown). Again, the reliability of the indication depends on the frequency of the species included in a subset, as reflected by the number of relevés that contain more than half of the indicator species. For example, among the ten replicate subsets with eight randomly selected indicator species, the number of correctly identified species-rich relevés (out of 23) ranges from 2 (subset where 6 relevés have ≥ 4 indicator species) to 19 (subset where 37 relevés have ≥ 4 indicator species). In all cases, only about half of the relevés with ≥ 4 indicator species are indeed particularly species-rich. This shows that finding at least half of the indicator species from a given subset can be used as a criterion for the identification and mapping of particularly species-rich pasture areas. However, this criterion is not highly reliable.

Conclusions

Our study has suggested that the most species-rich parts of Alpine pastures can be identified and mapped from the occurrence of selected indicator species despite the heterogeneity of this vegetation. This approach would deserve further development and testing in order to become a useful tool in ecological assessments. Our results further suggest that the set of indicator species to consider can be fairly small – including more than eight species hardly seems to improve the prediction provided that the species are sufficiently frequent. A major limitation of our study is that we used the same data to pre-select indicator species and to study how their number is related to species richness. For a better validation of the approach, it should be applied to pastures from different farms in the same region.

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