COMMUNITY ECOLOGY 5(1): 135-143, 2004
1585-8553 © Akadémiai Kiadó, Budapest

Data quality in monitoring plant species richness in Switzerland

M. Plattner[1], S. Birrer and D. Weber

Hintermann & Weber AG, Ecological Consultancy, Planning & Research, Hauptstrasse 52, CH-4153 Reinach BL, Switzerland. Fax: +41 61 717 88 89
[1] Corresponding author. E-mail: plattner@hintermannweber.ch

Keywords: Baseline monitoring, Biodiversity, Data quality, Field methods, Reproducibility, Species richness, Switzerland, Vascular plants.

Abstract: The on-going Biodiversity Monitoring in Switzerland Programme (BDM) has monitored vascular-plant species richness since 2001. This long-term programme focuses on two indicators at different spatial scales. First, the local diversity indicator monitors changes of species richness within habitats or types of land use (within-habitat diversity). Second, the landscape diversity indicator is utilized to describe landscape diversity (i.e., within-habitat mosaic diversity). Here we examine if the reproducibility of the BDM methods is sufficiently precise to detect future changes in species richness. We demonstrate that systematic methodical errors are negligible. Random errors that make changes more difficult to detect are also small. We calculate the Minimum Detectable Difference (MDD) for selected BDM strata using the variance of measured values. Then we deduce the MDD values for paired samples using data from grasslands and forests in the Canton Argovia. With 2.4 and 1.6 species they are promisingly precise. We develop a simple scenario for possible changes in species richness and show that they surpass the deduced MDD values by a factor four to six. We conclude that the BDM methods are appropriate for detecting future changes in species richness.

Abbreviations: BDM – Biodiversity Monitoring in Switzerland Programme; SD – standard deviation; MDD – minimum detectable difference; SAEFL– Swiss Agency for the Environment, Forests and Landscape; Z9 – local diversity indicator; Z7 – landscape diversity indicator.

Introduction

The *Biodiversity Monitoring in Switzerland Programme* (BDM) is a long-term monitoring programme of the Swiss Agency for the Environment, Forests and Landscape (SAEFL) which monitors vascular-plant species richness over time. This on-going monitoring, initiated in 2001, focuses on changes in species richness of selected taxa (Hintermann et al. 2000) and at different spatial scales (Weber et al. 2004). Of central importance to the programme is species richness on a local scale (i.e., within-habitat diversity) and on a landscape scale (i.e., within-habitat mosaic diversity) following the definitions of Whittaker et al. (2001). Because local diversity is strongly influenced by land-use, the local diversity indicator (mean species richness on 10 m^2, Z9) is suitable to describe changes in species richness within different types of land-use in the cultural landscape. The landscape diversity indicator (mean species richness on 1 km^2, Z7) measures landscape diversity, which is the result of heterogeneity within patches, within habitat types (i.e., types of land-use), and between types of the land-use as shown, for example, by Wagner et al. (2000), Whittaker et al. (2001) and Zechmeister and Moser (2001). In addition to vascular plants, other taxa are surveyed (e.g., snails, butterflies). For details see the Interim Report on the BDM by Hintermann et al. (2002)[1].

Because a long-term monitoring programme such as the BDM must guarantee data set comparability when data are separated by large spans of time, highly reproducible methods are needed to reduce, control and quantify imperfect detectability of species (Anderson 2001, Boulinier et al. 1998, Pollock et al. 2002, Yoccoz et al. 2001, Kéry and Schmid 2004). Species detectability is the crucial variable influencing reproducibility of Z7 and Z9. It is affected by three classes of variables (Buckland et al. 1993): (1) variables related to the observer, (2) variables related to the environment and (3) variables related to the species. The species and their properties might stay the same across years, as also environmental properties, but the observers will change over time. It is therefore important to know, to what extent species detectability is influenced by the observer. The BDM therefore invests significantly in developing and testing appropriate methods.

1 Further information on the BDM and actual datasets you will find under www.biodiversitymonitoring.ch.

Table 1. Summary of the BDM methodological characteristics for measuring vascular plant species richness.

Name Definitions follow Whittaker et al. 2001.	**Local diversity indicator Z9** Within-habitat diversity	**Landscape diversity indicator Z7** Within-habitat mosaic diversity
Methodological characteristic		
Sampling grid	Systematic, symmetrical	Systematic, symmetrical
Number of sampling units	1600	520
Sampling interval	Staggered survey over 5 years (each year a fifth of the entire sample)	Staggered survey over 5 years (each year a fifth of the entire sample)
Area surveyed per sampling unit	$10m^2$	$12'500m^2$
Shape of sampling units	Circle	Transect of 2,500m, 5m wide, along paths and streets in a 1x1km grid unit
Locating sampling areas	Differential GPS (real-time)	Map 1: 25,000
Marking of sampling areas	With a buried magnet and 3 above-ground surveyed colour markings	None, (in some cases colour markings)
Relocation of sampling areas	Magnetic detector, report	Map 1: 25,000
Sampling frequency	Every plot is visited once in the alpine and subalpine zone and twice a year at lower elevations; zones following *Wärmegliederung der Schweiz* (Schreiber et al. 1977).	Every transect is visited once in the alpine zone and twice a year at lower elevations; zones following *Wärmegliederung der Schweiz* (Schreiber et al. 1977).
Type of records	Presence/absence	Presence/absence
Recorded species	Vascular plant species. Some subspecies and microspecies are summarized in aggregations. Currently 3041 taxa (including all 216 aggregations).	Vascular plant species (same as for Z9) exept planted or sewed species on private properties, parks or other settlements.
Strata for routine interpretation	Routine interpretation of 10 types of land use (habitats): colline, montane and subalpine grassland; colline, montane and subalpine forest; arable land; settlements; alpine meadows; alpine vegetation. Other strata are possible.	6 main biogeographic regions of Switzerland (Gonseth et al. 2001; Fig. 1.) Other strata are possible.
Additional taxa recorded	Mosses, snails.	Breeding birds, butterflies.
Percentage of field budget for quality control	Approximately 10 % of costs for field work	Approximately 10 % of costs for field work

Furthermore, data quality is examined continuously by methods which are detailed below.

The research presented here aims to test whether the BMD methodology is appropriate for detecting future changes in species richness. We analyze data from the on-going survey, its quality control and some results of methodological tests. For both of the indicators Z9 and Z7 we examine the following questions:

- How reproducible are our species richness measurements?
- How precisely can changes in species richness be predicted?
- To what extent could mean species richness possibly change in the future?

Methods

Measuring changes in plant species richness

Since 2001 the BDM has routinely assessed vascular plant species richness on fixed surveying areas which are distributed systematically over Switzerland. The survey is staggered: each year one fifth of the entire sample for Z7 and Z9 is surveyed. Thus on the sixth year (2006) the first fifth of the areas will be re-assessed. Paired measures for all sampling units will be available after 10 years (2011).

Table 1 provides an overview of the most important methodological characteristics for Z9 and Z7. For more detailed information, see Hintermann et al. 2002.

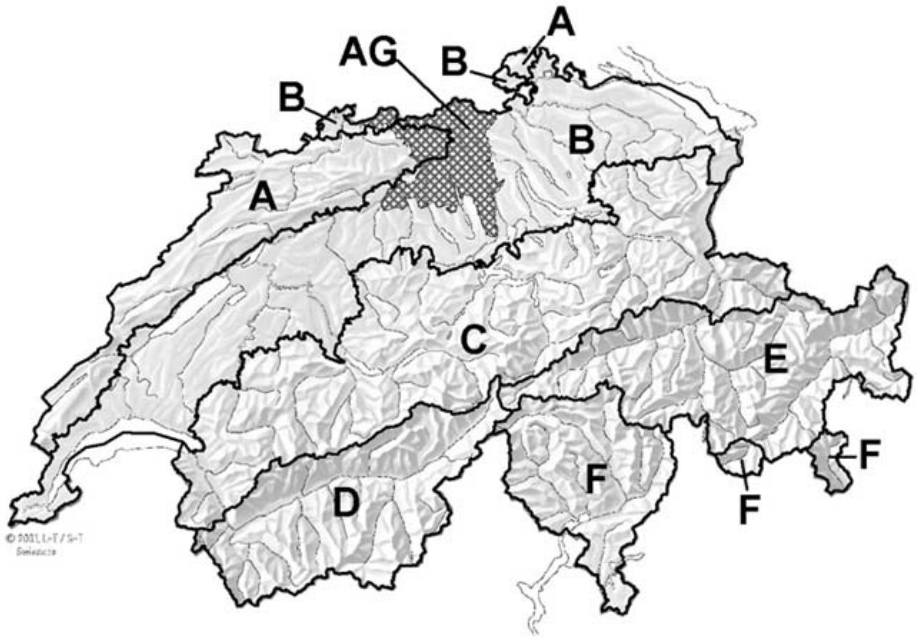

Figure 1. Study area. AG: Canton Argovia. The biogeographic regions of Switzerland (Gonseth et al. 2001) A: Jura, B: Central Plateau, C: Northern Alps, D: Western Central Alps, E: Eastern Central Alps, F: Southern Alps.

A fundamental methodological difference between Z7 and Z9 lies in the size and shape of the sampling plot. For Z9, the species richness in small circles of 10 m^2 is recorded. The exact centers of the circles that are defined by their coordinates are precisely located with a differential GPS. After the assessement, they are allocated to a single type of land use or habitat respectively. The landscape indicator Z7 is assessed along a 2.5 km transect with a total of 12,500 m^2 area. It represents a 1 km^2 grid unit with several different types of land use and habitats.

Evaluation of methods

Prior to the initial routine survey in 2001, methods were evaluated and tested for reproducibility and efficiency. Similar field data were previously assessed in the Canton Argovia (Fig. 1). Beginning in 1996, the Argovian survey consists of 517 Z9-sampling areas monitored with the same methods as the BDM (Weber 2002)[2]. A total of 73 paired measures were used to analyze the effects of paired samples (see below).

Routine survey

In 2001 and 2002, 13 botanists collected data from 493 Z9-sampling plots. The Z9 data are routinely interpreted for 10 types of land use (habitats) further differentiated by elevation. For Z7 in 2001 and 2002, a total of 184 transects were surveyed by 14 botanists. The Z7 data are routinely interpreted for the 6 main biogeographic regions of Switzerland (Gonseth et al. 2001, Fig. 1). In the Jura region and the Southern Alps, the sample size was doubled to allow more precise statements on the changes in species richness in these small regions.

Reproducibility of BDM-methods

The BDM invests approximately 10% of its annual field work budget on quality control. To test data quality, independent replicate surveys were performed on a part of the routine survey sample by 2 botanists who were not involved in the regular BDM survey. The regular BDM botanist team was unaware of which sample areas were replicated. This double sampling approach (Thompson et al. 1998, Pollock et al. 2002) allows not only a quantification of species detectability, but also of the reproducibility of Z7 and Z9 values.

Reproducibility is defined here as precision following Zar (1984). It is expressed by three indicators: (1) the difference of mean species richness between routine and control, (2) the mean of the absolute differences of species richness between routine and control and (3) the standard deviation (SD) of the differences of species richness be-

2 See also www.ag.ch/natur2001/alg/pages/natur/programme/mehrjahresprogramm/kontrollprogramm/LANAG.

Table 2. Results of 28 replicated sample plots from the Canton Argovia survey.

	Species
Mean species richness on 10 m^2, Botanist A	18.2
Mean species richness on 10 m^2, Botanist B	18.1
Difference of mean species richness (Botanist A - Botanist B)	0.1
Mean of the absolute differences of species richness between botanists A and B	2.5
SD of the relative differences of species richness between botanists A and B	3.3

Table 3. Results from 23 replicated BDM transects.

	Species
Mean species richness on 2'500 x 5 m, routine survey	250.1
Mean species richness on 2'500 x 5 m, control	255.1
Difference of mean species richness (Control - Routine)	5.0
Mean of the absolute differences of species richness between routine and control	19.7
SD of the relative differences of species richness between routine and control	23.4

tween routine and control. These indicators express different sources of data variability such as bias between observers (indicator 1) or random variability (indicators 2 and 3). To distinguish different kinds of random variability (e.g., data vs. random observer variability) further analysis would be necessary.

Local diversity indicator. In 2001 and 2002 the methods used in the BDM replicate collections for Z9 differed slightly from those used in the routine collection. The data were therefore inappropriate for determining methodological reproducibility. Instead, data originating from the Canton Argovia survey (see above) were used. In the Canton Argovia in the years 1997, 1999 and 2000, 28 sample plots were re-assessed by a second botanist one or two days after the regular assessement.

Landscape diversity indicator. In 2001 and 2002, the BDM performed an independent control survey on 23 transects with indicator Z7 using the same methods as the routine survey.

Precision at detecting changes in species richness

Assuming a *t*-distribution, the precision in detecting changes in species richness using the *minimum detectable difference* (MDD) was determined by the following equation (Zar 1984, p. 111):

$$\delta = [\ (s^2 / n)\ ]^{0.5} * (t_{\alpha(2),n} + t_{\beta(1),n}) \quad (1)$$

δ: minimum detectable difference,

s^2: variance of measured values,

n: sample size,

t: critical value of the *t*-distribution,

α: probability of committing a Type I error, and

β: probability of committing a Type II error.

Let $\alpha = 0.05$ and $\beta = 0.10$.

For some of the strata that were routinely analyzed for Z9 and Z7, we calculated the MDD values. We set the variance of species richness values as s^2, assuming that the variance of changes in species richness over time never surpasses spatial variance. To estimate s^2 for the entire sample, we used the values of the subsamples from 2001 and 2002.

For the paired measures from Canton Argovia, Equation (2) was used as follows (Zar 1984, p. 153):

$$\delta = [\ (s_D{}^2 / n)\ ]^{0.5} * (t_{\alpha(2),n} + t_{\beta(1),n}) \quad (2)$$

s_D^2: variance of pairwise differences.

Comparing MDD values with possible changes in species richness

To determine if the calculated MDD values will be useful in detecting future changes in species richness, we contrived the following scenario for demonstrating possible changes in species richness: We assumed the vegetation on an average sample plot is drifting to species poor or species rich condition. Species richness of the 'poor' vegetation was defined as the mean for the third of samples with the lowest species richness and 'rich' vegetation by the mean value for the third of samples with the highest species richness.

We used species richness data from the BDM 2001 and 2002 survey for *montane grassland* (indicator Z9) and the *Central Plateau* (indicator Z7). For both strata, we calculated the mean of all sample areas, the mean for the

Table 4. Means and SD of species richness of BDM Z9 plots and calculation of the MDD for the entire BDM sample using Equation (1) (n= sample size).

Habitat type and elevations	n (2001-2002)	Mean species richness (2001-2002)	SD (2001-2002)	n (entire sample)	MDD (entire sample)
Forest all elevations	163	19.7	10.7	420	1.7
Subalpine forest	45	23.4	11.8	115	3.6
Montane forest	94	18.1	9.8	240	2.1
Colline forest	24	18.3	9.8	65	4.0
Grassland all elevations	120	36.6	15.7	316	2.9
Subalpine grassland	40	47.8	16.7	105	5.3
Montane grassland	63	31.7	13.8	163	3.5
Colline grassland	17	28.7	12.6	48	6.0

Table 5. Means and SD of species richness of BDM Z7 transects and calculation of the MDD for the entire BDM sample using Equation (1) (n= sample size).

Biogeographical regions	n (2001-2002)	Mean species richness (2001-2002)	SD (2001-2002)	n (entire sample)	MDD (entire sample)
Switzerland	153	223	73.9	383	12.3
Jura*	16 (31*)	242	30.5	39 (78*)	11.3
Central Plateau**	39	220	32.2	98	10.6
Northern Alps	49	250	65.4	123	19.3
Western Central Alps	14	207	82.8	35	46.7
Eastern Central Alps	22	195	89.2	55	39.7
Southern Alps*	13 (27*)	221	97.0	33 (68*)	38.7

* region is sampled with doubled density
** only 1km^2 grid units with <50% water surface

third of samples with the lowest species richness and the mean for the third of samples with the highest species richness. We compared the differences between the three mean values to the calculated MDD values to assess the utility of our survey techniques in detecting future changes in species richness.

Results

Reproducibility of data

Although there are considerable differences in the values produced for single plots, resulting mean species richness values were very similar for the local diversity indicator Z9 in the Canton Argovia survey (Table 2). The same statement can be made on the landscape diversity indicator Z7 in the replicated BDM transects (Table 3).

Distribution of values and precision

There are not yet paired measures for the BDM programme. Therefore, the BDM estimated the precision in detecting changes in species richness using the variance, or the SD, of species richness.

In the local diversity indicator, the SD of the stated species richness values for grassland (meadows and pastures) was higher than the forest samples (Table 4). The precision in detecting future changes in species richness (MDD) was calculated using Equation (1).

In the landscape diversity indicator, a high degree of variability was found for the SD of the stated species richness values between biogeographic regions (**Table 5**). The MDD values using Equation (1) ranged from 10.6 species for the Central Plateau to 46.7 species for the Western Central Alps.

The effect of paired samples

From the Z9 survey in the Canton Argovia, there were paired measures for 73 sample areas in grasslands and forests. We used these data to demonstrate the effect of paired samples on the MDD. First, we calculated the MDD using the SD of species richness analogous to Tables 4 and 5 (Table 6.a). By calculating the MDD with the differences of species richness of the paired measures using Equation (2), the variance in the actual data set was

Table 6. a. Unpaired Samples: Means, SD and variances of species richness of Z9 plots collected and re-collected in the Canton Argovia. Calculation of the MDD for the entire sample using Equation (1). **b.** Paired Samples: Means, SD and variances of differences of species richness of Z9 plots collected and re-collected in the Canton Argovia. Calculation of the MDD for the entire sample using Equation (2). n= sample size.

a

Habitat type	Year of collection	n (sub-sample)	Mean species richness	SD (sub-sample)	Variance (subsample)	n (entire sample)	MDD (entire sample)
Forest	1996-1997	37	13.5	7.2	52.3	93	2.4
Forest	2001-2002	37	14.7	7.3	53.4	93	2.4
Grassland	1996-1997	36	21.5	8.3	69.1	90	2.8
Grassland	2001-2002	36	23.4	10.2	104.7	90	3.4

b

habitat type	Years of collection	n (sub-sample)	Mean Δ of species richness	SD (sub-sample)	Variance (subsample)	n (entire sample)	MDD (entire sample)
Forest	96/97-01/02	37	1.1	4.9	24.0	93	1.6
Grassland	96/97-01/02	36	1.9	7.1	51.0	90	2.4

Table 7. Means and SD of species richness of BDM Z9 plots and Z7 transects. Calculation of the MDD for the entire BDM sample, assuming that the variances were halved by the effect of paired samples, using Equation (2) (n= sample size). **a.** Local diversity indicator (Z9). **b.** Landscape diversity indicator (Z7).

a

Habitat type and elevations	n (2001-2002)	Mean species richness (2001-2002)	SD (2001-2002)	n (entire sample)	MDD (entire sample)
Forest all elevations	163	19.7	7.6	420	1.2
Subalpine forest	45	23.4	8.4	115	2.6
Montane forest	94	18.1	6.9	240	1.5
Colline forest	24	18.3	6.9	65	2.8
Grassland all elevations	120	36.6	11.1	316	2.0
Subalpine grassland	40	47.8	11.8	105	3.8
Montane grassland	63	31.7	9.7	163	2.5
Colline grassland	17	28.7	8.9	48	4.2

b

Biogeographical regions	n (2001-2002)	Mean species richness (2001-2002)	SD (2001-2002)	n (entire sample)	MDD (entire sample)
Switzerland	153	223	52.3	383	8.7
Jura*	16 (31)	242	21.6	39 (78)	8.0
Central Plateau**	39	220	22.8	98	7.5
Northern Alps	49	250	46.2	123	13.6
Western Central Alps	14	207	58.5	35	33.0
Eastern Central Alps	22	195	63.1	55	28.1
Southern Alps*	13 (27)	221	68.6	33 (68)	27.4

* region is sampled with doubled density

** only 1km^2 grid units with <50% water surface

Table 8. Species richness of vascular plants from the BDM survey in 2001 and 2002. (n: number of sample areas, min: minimum value, max: maximum value, mean low 1/3: mean of the third of sample areas with the lowest species richness/ 'poor vegetation', mean high 1/3: mean of the third of sample areas with the highest species richness/ 'rich vegetation'). **a.** Local diversity indicator (Z9); 10 m^2 plots. **b.** Landscape diversity indicator (Z7); 12,500 m^2 transects.

a

Habitat type and elevation	n	Species richness min	Species richness max	Species richness mean low 1/3	Species richness mean all	Species richness mean high 1/3
montane grassland	62	11	75	18.6	31.7	49.1

b

Biogeographical region	n	Species richness min	Species richness max	Species richness mean low 1/3	Species richness mean all	Species richness mean high 1/3
Central Plateau	39	155	290	184.7	220.2	255.7

considerably smaller. Reductions of the MDD by almost one species resulted (Table 6.b).

Table 7 shows modifications of Tables 4 and 5. We assumed that for BDM strata the variances were halved by the effect of paired samples. This resulted in a reduction of the MDD from 0.5 to 1.8 species (Table 7.a) for the shown Z9 strata. For Z7 strata the MDD was reduced by 3.1 up to 13.7 species (Table 7.b).

Species richness from the BDM survey 2001/02

To determine if the calculated MDD values will be useful in detecting future changes in species richness, we defined 'poor' and 'rich' vegetation. Table 8 shows species richness values of the routinely analyzed strata montane grassland (Table 8.a) and Central Plateau (Table 8.b).

Discussion

Reproducibility of species richness

For routine and control collections of the local diversity indicator Z9, we achieved a nearly identical mean of the species richness of 18.2 species (regular) and 18.1 species (control). Similarly, for the landscape indicator Z7, the difference of the means of the species richness was only 5 species with a mean of species richness of more than 250 species. This indicates the stated differences –that must be understood as methodical errors– were nearly random (neither control nor regularly team worked better on an average). Although the methods do not allow a one hundred percent species detectability, detectability seems more influenced by random environmental and species-specific phenomena than by the observer.

When discussing reproducibility, it is important to address random deviation of differences. Deviation can be seen as statistical noise that makes changes more difficult to detect. The SD of the differences of species richness was 3.3 species for Z9 and 23.4 species for Z7 (Tables 2 and 3). By comparing these to the SD values of the analyzed strata for Z9 and Z7 (Tables 4 and 5), we observed that the former are much smaller than the latter, which is a basic requirement for methodological reproducibility.

The BMD focuses on detecting changes in species richness. For Z9, we compared the difference of mean species richness (Table 2) to the mean difference of changes in species richness in the Argovian survey (Table 6). The difference of the mean species richness values achieved in the replicate collections were lower by a factor of ten than the changes in species richness observed in the Argovian survey between 1996/97 and 2001/02. If these changes can be confirmed in 2005 when paired measures for the entire Argovian sample are available, some relevant changes in biodiversity can be demonstrated at a highly significant level. To what extent such statements will be possible for BDM Z9 data or even for Z7 (because of a lack of data) cannot yet be tested.

Detecting changes in mean species richness

We also would like to discuss how precisely the BDM will be able detect future changes in mean species richness. The MDD for some selected Z9 and Z7 strata was calculated (Tables 4 and 5). The MDD determines the minimum size of changes that can be detected for a given variance and sample size. The BDM has yet to obtain paired measures. Alternatively, we used the variance of species richness from the 2001/2002 BDM subsample for the calculation (Equation 1). Some of the MDD values are encouragingly precise, but for some of the strata the values are only within reach by large, improbable changes in richness. It has to be noted that these are strata with a naturally high degree of spatial heterogeneity with regards to species richness, such as the alpine regions for Z7. Here the gain of precision by using paired measures will be particularly above average as we will demonstrate in the following section.

The advantage of paired samples

Analysis of the Argovian data showed that the variances of differences of species richness of paired samples (Table 6.b, Equation 2) were only half of the species richness variances (Table 6.a, Equation 1). We postulate that when examining future changes in the whole of Switzerland the effects of paired samples will be even greater, because the Argovian data originate from a small, relatively homogeneous region. The benefit of analyzing paired samples increases with the spatial heterogeneity of species richness in a stratum because the MDD value is calculated by the differences of the pair-wise measures (Equation 2). We assume, therefore, that for the BDM, current variances of species richness will be reduced by fifty percent when paired measures are available. Comparison of Tables 4, 5 and 7 shows that for Z9 strata the MDD will be reduced by up to 2 species (colline grassland) and for Z7 up to 14 species in the Western Central Alps.

Comparing MDD values with possible changes in species richness

Differences in species richness between sample areas can be caused by multiple factors such as soil pH (Ewald 2003), and other site conditions (Ellenberg et al. 1991, Wohlgemuth 1993), disturbance (Tiegs et al. 2004), or

natural hazards (e.g., windthrow, Palmer et al. 2000, Fischer et al. 2002). But the most important factor in a cultural landscape is the manner of land use, for example in different grassland types (Willems et al. 1993, Pauli 1998, Peintinger 1999, Fischer and Wipf 2002, Fischer et al., 2004) or in Middle European forests (Egloff 1991, Walther and Grundmann 2001, Dzwonko and Gawronski 2002).

The BDM is designed to detect changes in species richness over short periods, which are mainly caused by human interactions. In order to test and illustrate the precision that can be achieved, we assumed the vegetation on an average sample plot is drifting to species poor or species rich condition (Table 8). For montane grassland, with an overall mean of 32 species, this translated to a decrease of 13 species and an increase of 17 species. For Z7 Central Plateau, the differences between the mean values were about 35 species. Both strata montane grassland and Central Plateau are strongly influenced by human action. Therefore, 'poor', 'average' and 'rich' vegetation states can fluctuate between each other by changing the intensity and/or techniques of land use.

We compared the values in Table 8 to the MDD values in Table 7 and observed the expected MDD is approximately six times (Z9) and more than four times (Z7) smaller than the values from our scenario. This demonstrates that future changes for Z9 and Z7 will be detectable even if they are much smaller then our scenario values or if they only refer to a part of the sample areas.

Conclusions

These assumptions, based on the actual results, show that the reproducibility and the precision that can be achieved by BDM methods will be appropriate for detecting future changes in species richness.

Acknowledgements: We would like to thank Ch. Bühler and A. Zangger for discussion and assistance, the ALG (Baudepartement, Canton Argovia) for permission to use the Argovian survey data, Thomas Wohlgemuth, Scott Tiegs and an anonymous reviewer for their helpful comments on the manuscript. The research was supported by the Swiss Agency for the Environment, Forests and Landscape (SAEFL) and carried out by more than a dozen fearless botanists.

References

Anderson, D.R. 2001. The need to get the basics right in wildlife field studies. *Wildlife Society Bulletin* 29: 1294-1297.

Buckland, S.T., D.R. Anderson, K.P. Burnham and J.L. Laake. 1993. *Distance Sampling: Estimating Abundance of Biological Populations*. Chapman and Hall, London.

Boulinier, T., J.D. Nichols, J.R. Sauer, J.E. Hines and K.H. Pollok. 1998. Estimating species richness: The importance of heterogeneity in species detectability. *Ecology* 79: 1018-1028.

Dzwonko, Z. and S. Gawronski. 2002. Effect of litter removal on species richness and acidification of a mixed oak-pine woodland. *Biological Conservation* 106:389-398.

Egloff, F.G. 1991. Dauer und Wandel der Lägernflora. *Vierteljahrsschrift der Naturforschenden Gesellschaft Zürich* 136/4:207-270.

Ellenberg, H., H.E. Weber, R. Düll, V. Wirth, W. Werner and D. Paulissen. 1991. Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica* Volume 18. Verlag Erich Goltze KG, Göttingen.

Ewald, J. 2003. The calcareous riddle: Why are there so many calcicphilous species in the Central European flora? *Folia Geobotanica* 38:357-366.

Fischer, A., M. Lindner, C. Abs and P. Lasch. 2002. Vegetation dynamics in Central European forest ecosystems (near-natural as well as managed) after storm events. *Folia Geobotanica* 37:17-32.

Fischer, M. and S. Wipf. 2002. Effect of low-intensity grazing on the species-rich vegetation of traditionally mown subalpine meadows. *Biological Conservation* 104:1-11.

Fischer, M., J. Stöcklin, A. Weyand and K. Maurer. 2004 . Cultural and biological diversity of grasslands in the Swiss Alps. *Grassland Sciences in Europe*. In Press

Gonseth, Y., T. Wohlgemuth, B. Sansonnes and A. Butler. 2001. Die biogeographischen Regionen der Schweiz. Erläuterungen und Einteilungsstandard. Umwelt-Materialien Buwal 147:1-48.

Hintermann, U., D. Weber and A. Zangger. 2000. Biodiversity monitoring in Switzerland. *Schriftenr. Landschaftspflege Naturschutz* 62:47-58.

Hintermann, U., D. Weber, A. Zangger and J. Schmill. 2002. Biodiversity monitoring in Switzerland BDM – Interim Report. *Swiss Agency for the Environment, Forests and Landscape SAEFL*. Environmental Series No. 342.

Kéry, M. and H. Schmid. 2004. Monitoring programs need to take into account imperfect species detectability. *Basic and Applied Ecology* 5: 65-73.

Palmer, M.W., S.D. McAlister, J.R. Arévalo and J.K. DeCoster. 2000. Changes in the understory during 14 years following catastrophic windthrow in two Minnesota forests. *Journal of Vegetation Science* 11:841-854.

Pauli, D. 1998. Plant species diversity and productivity in wetland communities. patterns and processes. PhD thesis. Institut für Umweltwissenschaften, Universität Zürich.

Peintinger, M. 1999. The effect of habitat area and management on species diversity in montane wetlands. PhD thesis. Institut für Umweltwissenschaften, Universität Zürich.

Pollock, K.H, J.D. Nichols, T.R. Simons, G.L. Farnsworth, L.L. Bailey and J.R. Sauer. 2002. Large scale wildlife monitoring studies: statistical methods for design and analysis. *Environmetrics* 13: 105-119.

Schreiber, K.F., N. Kuhn, C. Hug, R. Häberli and C. Schreiber. 1977. Wärmegliederung der Schweiz. Eidg. Justiz- und Polizeidepartement, Bern.

Thompson, W.L., G.C. White and C. Gowan. 1998. *Monitoring Vertebrate Populations*. Academic Press, San Diego.

Tiegs, S.D., J.F. O'Leary, M.M. Pohl and C.L. Munill. 2004. Flood disturbance and riparian species diversity on the Colorado River Delta. *Biodiversity and Conservation*. In Press

Wagner, H.H., O. Wildi and K.C. Ewald. 2000. Additive partitioning of plant species diversity in an agricultural mosaic landscape. *Landscape Ecology* 15:219-227.

Walther, G.-R. and A. Grundmannn. 2001. Trends of vegetation change in colline and submontane climax forests in Switzerland. *Bulletin of the Geobotanical Institute ETH.* 67:3-12.

Weber, D. 2002. Langfristüberwachung der Artenvielfalt in den Nutzflächen des Kantons Aargau (LANAG). Die aktuellen Zahlen 2002. Unveröffentlicht, deponiert. Aarau, Baudepartement Kanton Aargau, Abteilung Landschaft und Gewässer.

Weber, D., U. Hintermann and A. Zangger. 2004. Scale and trends in species richness: considerations for monitoring biological diversity for political purposes. *Global Ecology and Biogeography* 13: 97-104.

Whittaker, R.J., K.J. Willis and R. Field. 2001. Scale and species richness: toward a general, hierarchical theory of species diversity. *Journal of Biogeography* 28:453-470.

Willems, J.H., R.K. Peet and L. Bik. 1993. Canges in chalk-grassland structure and species richness resulting from selective nutrient additions. *Journal of Vegetation Science* 4:203-212.

Wohlgemuth, T. 1993. Der Verbreitungsatlas der Farn- und Blütenpflanzen der Schweiz (Welten und Sutter 1982) auf EDV. Die Artenzahlen und ihre Abhängigkeit von verschiedenen Faktoren. *Botanica Helvetica* 103:55-71.

Yoccoz, N. G., J.D. Nichols and T. Boulinier. 2001. Monitoring of biological diversity in space and time. *Trends in Ecology & Evolution* 16: 446-453.

Zar, H.J. 1984. *Biostatistical Analysis*. Prentice-Hall, New Jersey.

Zechmeister, H.G. and D. Moser. 2001. The influence of agricultural land-use intensity on bryophyte species richness. *Biodiversity and Conservation* 10: 1609-1625.