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RESEARCH ARTICLE

Observer-driven pseudoturnover in vegetation monitoring is context-dependent but does not affect ecological inference

Steffen Boch[1] | Helen Küchler[1] | Meinrad Küchler[1] | Angéline Bedolla[1] | Klaus T. Ecker[1] | Ulrich H. Graf[1] | Tobias Moser[1] | Rolf Holderegger[1,2] | Ariel Bergamini[1]

[1]WSL Swiss Federal Research Institute, Birmensdorf, Switzerland

[2]Department of Environmental Systems Sciences D-USYS, ETH Zürich, Zürich, Switzerland

Correspondence
Steffen Boch, WSL Swiss Federal Research Institute, Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland.
Email: steffen.boch@wsl.ch

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Abstract

Aims: Resurveys of vegetation plots are prone to several errors that can result in misleading conclusions. Minimizing such errors and finding alternative approaches for analyzing resurvey data are therefore important. We focused on inter-observer error and excluded other sources of variation. Our main questions were: How large is the inter-observer error (i.e. pseudoturnover) in vegetation surveys, and can it be reduced by simple data aggregation approaches? Which factors are affecting pseudoturnover and does it vary between morphological species groups or change over time? Is ecological inference robust against inter-observer differences?

Location: Switzerland.

Methods: Over seven years, we double-surveyed a total of 224 plots that were marked once in the field and then sampled by two observers independently on the same day. Both observers conducted full vegetation surveys, recording all vascular plant species, their cover, and additional plot information. We then calculated mean ecological indicator values and pseudoturnover.

Results: Average pseudoturnover was 29% when raw species lists were compared. However, by applying simple aggregation steps to the species list, pseudoturnover was reduced to 17%. Pseudoturnover further varied among habitat types and declined over the years, indicating a training effect among observers. Most overlooked taxa, responsible for pseudoturnover, had low cover values. Mean ecological indicator values were robust against inter-observer differences.

Conclusions: To minimize pseudoturnover, we suggest continuous training of observers and species-list aggregation prior to analysis. As mean ecological indicator values were robust against inter-observer differences, we conclude that they can provide a reliable estimate of temporal vegetation and ecological changes.

KEYWORDS
dry grassland, ecological indicator value, fen, flood plain, inter-observer difference, long-term biodiversity monitoring, observer error, pseudoturnover, raised bog, vegetation survey

1 | INTRODUCTION

In the past decades, the extent, quality and biodiversity of many habitat types declined strongly because of negative human impacts (Janssen et al., 2016; Visconti et al., 2018). To document and to better understand such temporal changes, national monitoring programs, in which permanent vegetation plots are investigated on a regular basis, are suitable instruments. Today, statistically designed monitoring programs that are systematically conducted and stringently replicated are gaining relevance from a scientific, practical and political point of view. Because of their increasing importance for biological conservation and natural resource management, numerous programs that rely on permanent vegetation plots have been established across Europe in the past few decades (e.g. Weber et al., 2004; Nichols & Williams, 2006; Milberg et al., 2008; Tomppo et al., 2010; Corona et al., 2011; Bergamini et al., 2019; Meier et al., 2021). In addition to coordinated monitoring programs, resurveys of historical vegetation plots, i.e. plots initially recorded before major environmental changes occurred, have become an important tool to detect vegetation and environmental changes across time (e.g. Hedwall & Brunet, 2016; Hédl et al., 2017; Verheyen et al., 2017; Charmillot et al., 2021; Kummli et al., 2021; Simons et al., 2021).

Despite the high relevance of resurvey data for interpreting temporal changes in biodiversity, ecology and conservation management, resurveys are prone to several shortcomings that can affect data and subsequently result in misleading conclusions or management recommendations (Ross et al., 2010; Kapfer et al., 2017). One shortcoming that often cannot be excluded in resurveys of historical vegetation plots is relocation error, i.e. shifts in plot position and therefore in the included vegetation (Kapfer et al., 2017; Verheyen et al., 2018; Boch et al., 2019). This type of error can only be avoided by using permanently marked plots, a method that enables the exact relocation of plots (Bakker et al., 1996) and is now widely used in monitoring programs (e.g. Bergamini et al., 2019; Fischer & Traub, 2019).

A further shortcoming of resurveys that cannot be fully avoided is observer error (e.g. Lepš & Hadincová, 1992, Vittoz & Guisan, 2007, Milberg et al., 2008, Archaux, 2009, Verheyen et al., 2018, Lisner & Lepš, 2020; reviewed in Morrison, 2016). Two observer error types can be distinguished: while the less well-studied intra-observer error refers to different results of the same observer at different times (e.g. Morrison, 2016; Lisner & Lepš, 2020), the inter-observer error refers to different results from two or more observers. In this study, we focused on the inter-observer error, which is multifaceted as observers differ in species knowledge and in their experience in conducting vegetation surveys (an error that might decrease with time in long-term projects), but also includes personal biases such as mental fatigue and physical stress (Morrison, 2016). Species lists of vegetation plots that were compiled on the same day but by different observers usually differ from each other to a certain degree. The well-studied phenomenon describing inter-observer differences between species lists from the same plot is called pseudoturnover, i.e. the amount of shared and differing taxa (Nilsson & Nilsson, 1985). In a review of 59 studies providing quantitative estimates of observer error, Morrison (2016) reported that up to 30% of species were not recorded by both observers of the same plot (or even 36%; see Morrison et al., 2020). This error can be largely attributed to the overlooking of species but also, to a lesser extent, to misidentification (Lisner & Lepš, 2020; Morrison et al., 2020). The detectability of species has been proposed to play a major role in this probability of being overlooked. Detectability can be influenced by population size, morphology and phenology (Garrard et al., 2013; Bornand et al., 2014; Dennett & Nielsen, 2018). In addition, there are other factors that can affect pseudoturnover, including seasonal vegetation changes (Kirby et al., 1986; Kapfer et al., 2017), plot size (larger plots have higher pseudoturnover; e.g. Seidling et al., 2014, Morrison et al., 2020) or vegetation structure (e.g. dense vs open vegetation; Vittoz & Guisan, 2007).

Verheyen et al. (2018) concluded that the accuracy of resurveys is largely unknown. They thus called for further investigation and the introduction of measures to increase the precision of vegetation plot data. First, Burg et al. (2015) showed that the actual compositional changes of vegetation plots observed after one century can be three times higher than the observer-driven pseudoturnover. Nevertheless, in resurvey studies covering shorter time periods, e.g. less than 10 years, it is likely that the observer error is more substantial, possibly equaling or even exceeding actual vegetation changes (Futschik et al., 2020). However, the magnitude of this pseudoturnover over shorter time-scales is largely unknown. Second, it has not yet been systematically explored whether observer-related pseudoturnover can be reduced by applying simple data aggregation approaches prior to analysis, e.g. by merging herb, shrub and tree layers, by setting subspecies to the species level, or by assigning species to aggregates. Third, as studies investigating observer error have mostly been conducted in one particular year or with varying observer teams across time, it remains unclear whether observer-related pseudoturnover declines with time within a group of observers, thanks to their continuous training in species identification and their increasing experience in conducting vegetation records. Fourth, most studies investigating observer differences in vegetation sampling have been carried out in a single region or even in a single habitat type (e.g. Verheyen et al., 2018; Morrison et al., 2020). They thus have largely excluded environmental variation and variation in species richness among plots. While observer effects in forests and grasslands have been studied before, flood plains and wetlands, including fens and raised bogs, are underrepresented or even absent from the literature (Morrison, 2016). Thus, it is largely unknown whether pseudoturnover varies across different habitat types, e.g. species-rich dry grasslands vs species-poor raised bogs (but see Morrison et al., 2020 for a study of three wetland types).

Ecological indicator values describe the realized niche optimum of a species on an ordinal scale (Ellenberg et al., 2001; Landolt et al., 2010). Averaging values over all species in a plot yields

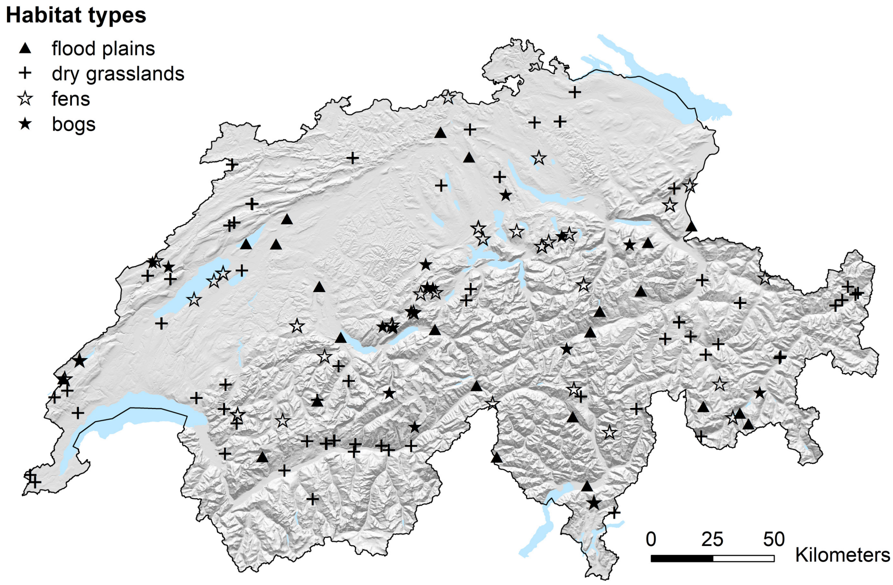

FIGURE 1 Location of the 224 double-surveyed plots in the 129 sites of national importance covering the four major habitat types across Switzerland

information on the environmental conditions of a site (Tölgyesi et al., 2014). Ecological indicator values describe longer-term site conditions even better than exact point measurements (Wamelink et al., 2002), making them particularly suitable for detecting ecological changes (Diekmann, 2003; Küchler et al., 2018). Mean ecological indicator values have been shown to be relatively robust to relocation error (Boch et al., 2019). They might increase the accuracy of plot data even further if they are proven robust to pseudoturnover as well, but this has yet to be explored (but see Ewald, 2003 for effects of species-list completeness on mean indicator values, and Futschik et al., 2020 for observer effects on a thermal vegetation indicator).

In this study, we examined inter-observer error in vegetation surveys conducted in the framework of the long-term program "Monitoring the effectiveness of habitat conservation in Switzerland". The program was established to monitor changes in nationally important habitats. Over seven years, we double-surveyed 224 circular plots of 10 m^2 that were distributed over 129 sites of national importance, encompassing four major habitat types (flood plains, fens, raised bogs and dry grasslands) across Switzerland to explore observer differences across habitat types and time. By assigning two different observers to survey permanently marked plots on the same day, we excluded several error sources, such as relocation error, plot size differences, seasonal changes in vegetation composition, and phenological differences. Our main questions were:

1. How large is the inter-observer error (i.e. pseudoturnover) in vegetation surveys, and can it be reduced by simple data aggregation approaches?
2. Is pseudoturnover affected by the cover of species in a plot, does it vary between morphological species groups, vegetation structures and major habitat types, and does it change over time?
3. Are ecological indicator values robust against inter-observer differences?

2 | METHODS

2.1 | The monitoring program "Monitoring the effectiveness of habitat conservation in Switzerland (WBS)"

In 2011, the Swiss Federal Office for the Environment (FOEN) and the WSL Swiss Federal Research Institute launched the monitoring program "Monitoring the effectiveness of habitat conservation in Switzerland (WBS)" to observe developments and changes at about 7000 sites of national importance that cover about 2.3% of the national territory. These sites are legally protected and include raised bogs, fens, dry grasslands, and flood plains, as well as amphibian breeding sites. The WBS is operated as a long-term program and combines remote-sensing approaches and extensive floristic and faunistic field surveys. Based on the gathered data, indicators are calculated to evaluate whether the sites are developing in line with their conservation targets, i.e. whether the area and quality of habitats is maintained (Bergamini et al., 2019).

For vegetation surveys, a weighted subsample of about 800 sites was selected out of the pool of 7000 sites of national importance using a complex sampling design, which gave more weight to rare vegetation types and small biogeographic regions than to common vegetation types and larger biogeographic regions in Switzerland (Tillé & Ecker, 2014; Bergamini et al., 2019). Within these 800 sites, about 7000 plots were randomly chosen, with rare vegetation types given more weight than common ones (for details see Tillé & Ecker, 2014). In the field, we used a high-accuracy real-time differential GPS (Trimble Geo 7X H-Star with minimum 10 cm accuracy after post processing; Trimble Inc., Westminster, USA) to locate the preselected plot centers. We then permanently marked the center of each plot 10–30 cm below ground with a magnetic probe to ensure future relocation with magnet detectors. The final plot center coordinates were further measured with the high-accuracy GPS (>150 measurements per plot; Bergamini et al., 2019).

2.2 | Vegetation sampling, double surveys and plot data

In long-term monitoring programs, the consistent high quality and reproducibility of vegetation surveys are mandatory requirements to ensure reliable analyses of temporal vegetation changes. We applied various measures to minimize observer effects (Morrison, 2016). Specifically, we minimized systematic spatial, temporal and habitat-specific observer biases by using all observers at different times of the vegetation period, in all major habitat types, and in all biogeographic regions of Switzerland. Furthermore, species belonging to critical species groups that are difficult to identify were collected and identified together after field work. We also conducted excursions and field courses on a regular basis to improve the observers' species knowledge and identification skills. During the field season, we further carried out weekly double surveys of plot pairs.

From 2014 to 2020, we double-surveyed a total of 224 circular 10-m^2 plots (Figure 1). The 224 plots were distributed over 129 sites of national importance across Switzerland to explore observer differences across major habitat types (Figure 1), i.e. 22 flood plains (N = 36 double-surveyed plots), 32 fens (N = 57), 18 raised bogs (N = 27), and 57 dry grasslands (N = 104; see also Appendix S1). The two plots for the double surveys were selected in the morning by the field team (two persons) before they arrived on site. A map was used as the basis for the selection and the main criterion for the selection was a short distance between the two plots. In total, 19 professional botanists with a profound knowledge of the Swiss flora and experience in vegetation surveys were involved (see also Appendix S2).

Each double-surveyed plot was marked only once in the field and then sampled by the two observers independently on the same day, one immediately after the other. Observers had no restrictions regarding survey time and were instructed to identify taxa to the lowest level possible. As both observers were aware of the double survey, it might be that observers were more thorough than in "regular" plots and that pseudoturnover was underestimated in the present study. In each plot, we recorded all occurring vascular plant species that had shoots growing in the plot. In the case of larger woody plants, at least 50% of the stem area at ground level had to be within the plot to be included. Cover was estimated for each species using a modified Braun-Blanquet scale (r, ≙<0.1%; +, ≙0.1% to <1%; 1, ≙ 1% to <5%; 2, ≙ 5% to <25%; 3, ≙ 25% to <50%; 4, ≙ 50% to <75%; 5, ≙ 75% to <100%). We further distinguished between three vegetation layers: herbs (herbaceous plants of any size, and woody species <0.5 m in height), shrubs (woody species 0.5–3 m in height) and trees (woody species >3 m in height), meaning that a woody species could be recorded in all three layers simultaneously. In addition, we estimated the percentage of the plot area covered by all vegetation. The two observers later compared the two surveys and discussed differences concerning species identification and cover estimations, but without correcting differences between the two surveys. In this way, we aimed to achieve a training effect, further equalizing observer differences in species identification knowledge over time. As effects of seasonality and relocation error could be excluded with the approach we used, the data were well suited to estimating observer-driven pseudoturnover.

2.3 | Mean ecological indicator values

We calculated mean indicator values for nutrients (N), light (L), temperature (T), continentality (K), moisture (F), reaction (R) and humus (H) for each survey based on Landolt et al. (2010) using the program Vegedaz (Küchler, 2019). We only present results of the arithmetic mean of the indicator values rather than the cover-weighted means, as results of the two approaches were qualitatively similar.

2.4 | Data preparation and statistical analysis

Statistical tests were performed in R version 4.1.2 (R Core Team, 2021) and Vegedaz (Küchler, 2019). We calculated the pseudoturnover of taxa between the two surveys of each plot using Sørensen dissimilarity (Sørensen, 1948): pseudoturnover = $(b+c)/(2a+b+c)$, where b is the number of taxa present in the first survey but not in the second, c is the number of taxa present in the second but not in the first survey, and a is the number of taxa present in both surveys. The Sørensen dissimilarity index multiplied by 100 is identical to the often-used measure of turnover according to Nilsson and Nilsson (1985). Pseudoturnover thus refers to the percentage of species overlooked by either of the two observers.

We then stepwise aggregated the species lists to test whether pseudoturnover can be minimized by data aggregation. We therefore calculated pseudoturnover: (1) for the raw species list where we considered the same species in different layers as different species in the calculations; (2) after merging the shrub and tree layers (i.e. when the two observers categorized the same woody species individual differently, as either a shrub [0.5–3 m height] or a tree [>3 m height], because its height was around 3 m); (3) after merging all layers (i.e. herb, shrub and tree); (4) after reducing uncertainly identified species, i.e. merging taxa that were identified by one observer to the species level but more cautiously by the other observer, i.e. with "cf." (e.g. merging entries *Festuca* cf. *laevigata* and *Festuca laevigata*); (5) after removing subspecies (e.g. merging entries *Festuca laevigata* subsp. *crassifolia* and *Festuca laevigata*); and (6) after setting all species forming an aggregate to the aggregate level (based on the aggregates listed in Landolt et al., 2010; e.g. merging entries *Festuca laevigata* and *Festuca ovina* aggr.). We calculated pseudoturnover for each plot and aggregation step (Table 1). We then analyzed the difference in pseudoturnover between each further aggregation step and the previous one using paired Wilcoxon tests (Figure 2).

Using the fully aggregated species list, we conducted further analyses to test which factors affect pseudoturnover. We calculated pseudoturnover separately for two morphologically different groups: (1) graminoids (Poaceae, Cyperaceae, Juncaceae) and (2)

TABLE 1 Mean pseudoturnover between two observers of the same plots and percentage of shared taxa (±SE) for each aggregation step

	Pseudoturnover (%)		Shared taxa (%)	
	Mean	SE	Mean	SE
Raw lists	28.5	0.71	56.7	0.01
Woody layers merged	28.5	0.72	56.7	0.01
All layers merged	28.0	0.74	57.5	0.01
Uncertainty removed	26.3	0.72	59.5	0.01
Without subspecies	21.8	0.62	65.1	0.01
Species aggregated	16.6	0.54	72.3	0.01

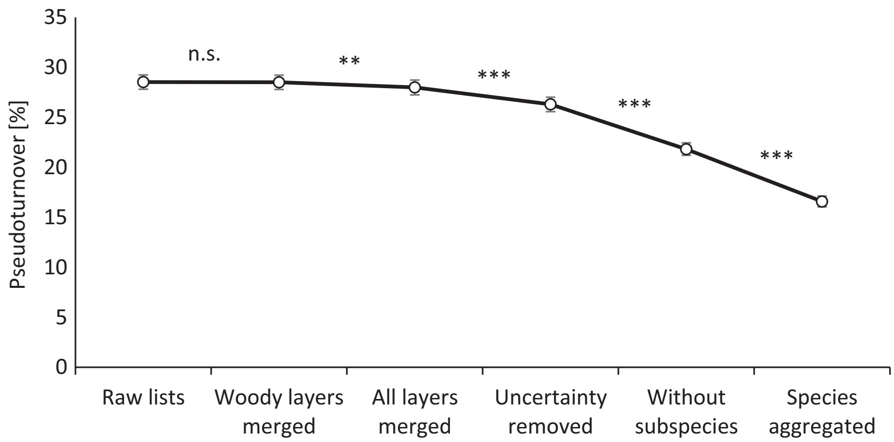

FIGURE 2 Pseudoturnover of taxa between two observers of the same plots ($N = 224$ plots) across aggregation levels. The difference in pseudoturnover from one aggregation step to the next was analyzed using paired Wilcoxon tests (***, $p < 0.001$; **, $p < 0.01$; n.s.: $p \geq 0.05$)

TABLE 2 Summary of the linear mixed-effects model with site ID code fitted as random factor, separating the effects of habitat type, observation year, vegetation cover, species richness and percentage of low-cover species, as well as the interaction between habitat type and observation year, on pseudoturnover (analysis of the fully aggregated species list)

	df	Sum sq	Mean sq	*F*	*p*
Habitat type	3	355.20	118.40	2.75	**0.0455**
Vegetation cover	1	3.47	3.47	0.08	0.7769
Species richness	1	165.04	165.04	3.83	0.0519
Percentage of low-cover species	1	477.00	477.00	11.07	**0.0010**
Observation year	1	539.43	539.43	12.52	**<0.001**
Habitat type × observation year	3	199.85	66.62	1.55	0.2050
R^2_m 0.188; R^2_c 0.379					

Note: R^2 is given as the marginal coefficient of determination (R^2_m; proportion of variance explained by fixed factors alone) and the conditional coefficient of determination (R^2_c; proportion of variance explained by both fixed factors and the random factor). Significant differences are indicated with bold *p*-values ($p < 0.05$).

other taxa in each plot. We tested whether pseudoturnover between these two morphological groups differed significantly using paired Wilcoxon tests, i.e. testing whether pseudoturnover was driven by differences in graminoid species between observers (e.g. Dennett & Nielsen, 2018). To explore why a taxon was overlooked by one of the observers, we separated the number of observations summed across all plots per Braun-Blanquet cover category into shared taxa between the two observers and taxa that were overlooked by either one of the two observers. In addition, we used a linear mixed-effects model (*lmerTest*R package; Kuznetsova et al., 2017) to test the effects on pseudoturnover attributable to: (1) habitat type (flood plain, fen, raised bog and dry grassland); (2) total vegetation cover (i.e. whether more taxa were overlooked in densely vegetated plots); (3) average species richness per plot recorded by observers 1 and 2 (i.e. whether the chance of overlooking taxa was higher in species-rich plots than in species-poor ones); (4) mean percentage of low-cover species (taxa with a cover of <1% of the plot area; Braun-Blanquet categories "r", "+" and "1") out of the total species count per plot recorded by observers 1 and 2 (i.e. whether species with a low cover were more likely to be overlooked); and (5) observation year (2014–2020; as an indication of an increase in species knowledge of the observers because of training effects over time). We fitted site ID code as a random factor to account for site-specific differences. To avoid differences in the variance among factors and to improve model convergence, we first standardized all continuous variables (2–5) to a mean of 0 and standard deviation of 1. As some of the observers started their work in the monitoring program with more experience in mires than in dry grasslands, we additionally included the interaction between habitat type and observation year to test whether observer differences were consistent over time and across habitat types. Model assumptions were checked visually by plotting residuals vs predicted values and with normal-quantile plots. We present the type III model summary with Kenward–Roger approximation (Table 2). We calculated R^2 as the marginal coefficient of determination (proportion of variance explained by fixed factors alone) and the conditional coefficient of determination (proportion of variance explained by both fixed factors and the random factor) for mixed-effects models (Nakagawa & Schielzeth, 2013; *MuMin* R package: Barton, 2020; Table 2).

To analyze the effects of the observers on mean ecological indicator values, we first ordered the double-surveyed plots by original species counts and then calculated differences in mean indicator values between the two observers' surveys by subtracting the mean indicator values of the survey with the lower species count from those of the survey with the higher species count. We did this for raw species lists, as well as for all the above-mentioned aggregation steps. We then used Wilcoxon tests to evaluate if these differences were significantly different from zero. As we never found significant differences in mean indicator values between observers, we only present the results of the fully aggregated species list (Table 3). Analyzing effects of observers on mean indicator values separately for the four habitat types yielded qualitatively similar results (except of significant differences for continentality and reaction in fens, but only when the fully aggregated species list was analyzed). We therefore do not present or discuss these results further.

3 | RESULTS

3.1 | Quantifying pseudoturnover across aggregation levels of species lists

When comparing raw species lists as they were compiled in the field, the average pseudoturnover was high at 29% (Figure 2, Table 1). However, we found that pseudoturnover could be reduced by applying aggregation steps to the species lists. Overall, the five aggregation steps reduced the average pseudoturnover to 17%. The strongest reduction in pseudoturnover was achieved by setting subspecies to the species level (minus 4.5% pseudoturnover) and by setting species to the aggregate level (minus 5.2% pseudoturnover; Figure 2, Table 1).

TABLE 3 Results of paired Wilcoxon tests on inter-observer differences in mean ecological indicator values

Mean ecological indicator value	*p*	Mean change	SE
Moisture	0.417	−0.001	0.005
Humus	0.083	0.007	0.006
Continentality	0.052	−0.006	0.004
Light	0.343	−0.004	0.006
Nutrients	0.398	0.004	0.006
Reaction	0.493	−0.003	0.006
Temperature	0.489	0.004	0.006

Note: As inter-observer differences were very similar between levels of aggregation, only the results of the fully aggregated species list are presented.

3.2 | Pseudoturnover and cover of taxa, morphological species group, vegetation structure, habitat type, and time

We found no differences in pseudoturnover between two morphological species groups, i.e. graminoids and non-graminoids (mean difference ± SE = 2.01 ± 1.21, $p = 0.186$). The cover of a particular taxon in a plot seems to be one of the most important factors explaining why it may be overlooked by one of the observers: the number of overlooked taxa was highest for the first two cover categories "r" (<0.01 m^2 cover in a 10-m^2 plot; 1012 observations summed across all plots and overlooked by either one of the observers) and "+" (0.01 to <0.1 m^2 cover; 941 observations overlooked), low for categories "1" (0.1 to <0.5 m^2 cover; 210 observations overlooked) and "2" (0.5 m^2 to <2.5 m^2; 63 observations overlooked), negligible for categories "3" (2.5 m^2 to <5.0 m^2; four observations overlooked) and "4" (5 m^2 to <7.5 m^2; two observations overlooked), and absent for category "5" (7.5 m^2 to <10 m^2; no observations overlooked; Figure 3). These results mean that 87.5% of the overlooked observations (1953 of the total 2232 overlooked observations) could be attributed to taxa with a cover of <1% of the plot area. Our linear mixed-effects model further showed that pseudoturnover increases as the percentage of low-cover species out of the total species count in a plot increases (Table 2; estimate 2.5 ± 0.75; *t*-value 3.35).

In addition, pseudoturnover differed marginally significantly among the four habitat types (Table 2), with highest mean pseudoturnover values occurring in dry grasslands (not significantly different from flood plains, but significantly different from the other two major habitat types), intermediate mean values in flood plains and fens, and lowest mean values (significantly different) in raised bogs (Figure 4). The percentage of overlooked taxa out of the total number of taxa followed a similar pattern regarding habitat type (Figure 5).

The vegetation structure (total vegetation cover) of the plots had no effect on pseudoturnover (Table 2). The effect of species richness of the plots on pseudoturnover was just not significant (Table 2; estimate −1.70 ± 0.86; *t*-value −1.97), despite differences in species richness among the four habitat types (Figure 5). Interestingly, pseudoturnover declined over the observation years (estimate −2.94 ± 1.35; *t*-value −2.18), suggesting a training effect of the observers. This effect was consistent across habitat types, as indicated by the non-significant interaction between habitat type and observation year (Table 2).

3.3 | Ecological indicator values and inter-observer differences

We found no significant differences in any of the mean ecological indicator values between observers (Table 3). Differences in mean

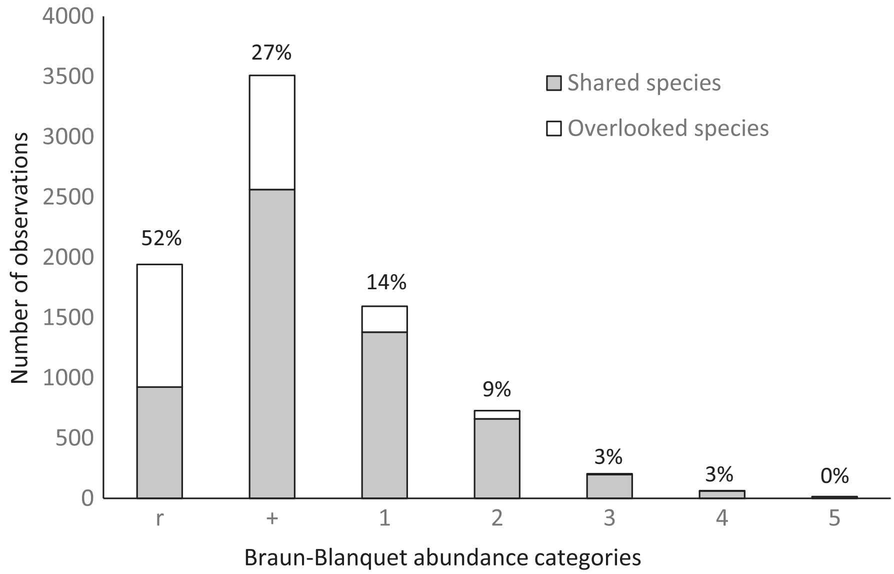

FIGURE 3 Total number of observations summed across the 224 double-surveyed plots per Braun-Blanquet cover category, separated into shared taxa (recorded by both observers) and taxa that were overlooked by either one of the two observers (results of the fully aggregated species list). The percentage of overlooked taxa out of the total number of observations per cover category is also given

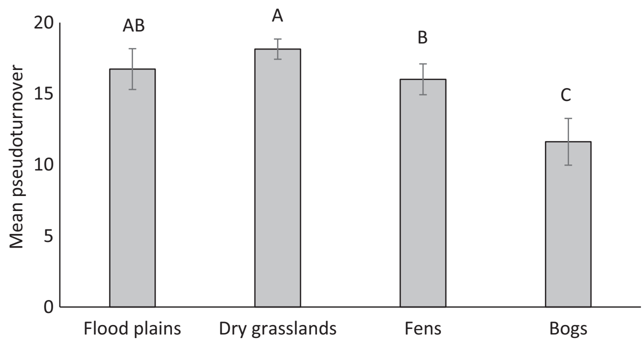

FIGURE 4 Mean pseudoturnover (±SE) in 224 double-surveyed plots across four habitat types (results of the fully aggregated species list). Different letters denote significant differences in pseudoturnover between habitat types at $p < 0.05$ (based on Wilcoxon tests)

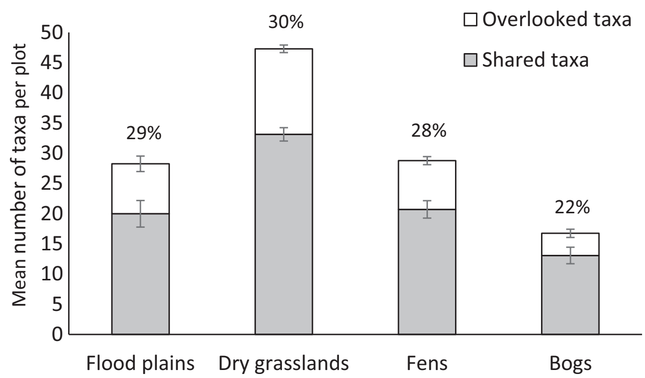

FIGURE 5 Mean number (±SE) of shared taxa (recorded by both observers) and taxa that were overlooked by either one of the two observers across the four habitat types (results of the fully aggregated species list). Also given is the percentage of overlooked taxa out of the total mean number of taxa per habitat type

continentality and, to a lesser degree also mean humus value, were, however, close to statistical significance. This indicates that despite the strong pseudoturnover, ecological indicator values are generally robust to inter-observer errors.

4 | DISCUSSION

4.1 | Reduction in observer-driven pseudoturnover by species-list aggregation and observer training

In comparison to the magnitude of pseudoturnover of 10%–36% reported in previous studies covering various survey settings and habitat types (e.g. Morrison et al., 2020; reviewed in Morrison, 2016), the average value of 29% for the comparison of raw species lists in our study was rather high. In addition, the mean percentage of shared taxa of only 57% for raw species lists was relatively low and exactly the same value (57%) was reported by Scott and Hallam (2002), who studied inter-observer errors by double-surveying plots within the United Kingdom Environmental Change Network. However, Scott and Hallam (2002) did not account for different vegetation layers, focusing more on misidentifications instead. The lower values of pseudoturnover reported in other studies were mostly caused by systematically excluding misidentifications. For instance, Verheyen et al. (2018), who investigated inter-observer and relocation errors in temperate forests in 10 European regions, aimed to reduce misidentification errors by conducting a first survey with an experienced botanist and by having experienced observers double-check all species' identifications. They found an average pseudoturnover (excluding relocation and misidentification errors) of 21%. Groom and Whild (2017) evaluated the accuracy of species lists regarding "false-positive observations", i.e. misidentifications, by comparing a species list recorded by a "normal" observer to a list recorded by a "gold standard" observer. More convincing than this method of relying on the accuracy of a single experienced observer, Archaux (2009) quantified the misidentification error of plots in French deciduous forests, which were surveyed by only one observer, by comparing the records to "consensual species lists" compiled by a team of several observers who surveyed the same plots. Similarly, Scott and Hallam (2002) used a survey by a third observer to quantify the misidentification error between two other observers.

Our results demonstrate that the magnitude of pseudoturnover can be strongly reduced, from 29% to an intermediate to low value of 17% (Morrison, 2016) through simple stepwise species-list aggregation. While merging all vegetation layers resulted in only a moderate pseudoturnover reduction (by about 0.5%), removing uncertain identifications led to a further reduction by 1.7% (Table 1), which is partly comparable to the "cautious error" (i.e. one observer identified a plant to the species level and the other identified it only to the genus level) used in several other studies (e.g. Morrison et al., 2020, 2020). Our value of 1.7% is within the range of values reported by Morrison et al. (2020, 2020), who quantified the cautious error to be, on average, around 1% and 1.4% for double-surveyed plots in wetland habitats in Ohio (USA) and in prairie grasslands in Kansas (USA), respectively. Notably, after the above-mentioned aggregation steps, removing subspecies and further setting species to the aggregate level yielded the largest overall reductions in pseudoturnover in our study, by 4.5% and 5.2%, respectively. In other studies, these steps were a priori excluded because plants were identified only to the species level and then aggregated only to the genus level (Morrison et al., 2020).

In our study, pseudoturnover declined over the years of observation, indicating a training effect of the observers. This effect was consistent across the four habitat types, as indicated by the non-significant interaction between habitat type and observation year, and therefore cannot be attributed to the more extensive experience of some observers in conducting vegetation surveys in mires than in dry grasslands at the beginning of the program. Based on the review by Morrison (2016), such training effects seem to be common in vegetation surveys. However, he mentioned that training is likely to have a greater potential to increase precision among less-experienced observers. In our program, a training effect is also visible in the overall set of 7000 plots, as in many cases plants that had been recorded on the aggregate level at the beginning of the program were later recorded at the subspecies level (unpublished result), indicating improved species knowledge of the team of observers over time. However, our results of overlooking species even with high cover values that can either be attributed to misidentification or personal biases such as mental fatigue and lack of concentration also demonstrate that the observer error cannot be fully avoided.

4.2 | Factors affecting observer-driven pseudoturnover

In line with other studies, we found that species with very low coverage were particularly overlooked (Figure 3; 87.5% of the overlooked observations out of the total number of overlooked observations had a cover of <1%) and that an increasing percentage of low-cover species increased pseudoturnover (Table 2). This result confirms the findings of Vittoz and Guisan (2007), who studied inter-observer differences in Swiss alpine meadows and likewise found that the majority of overlooked species had low cover values. Similarly, Milberg et al. (2008) and Morrison et al. (2020), who studied inter-observer differences during resurveys of permanent plots in Swedish boreal forests and in wetland habitats in Ohio (USA), respectively, reported that most species that were overlooked in double surveys were in the two lowest cover classes. Likewise, Dennett and Nielsen (2018), who studied graminoids vs other life forms in *Carex*-rich vegetation types of Alberta (Canada), found that the abundance of a species was one of the most important factors predicting its detectability. Other studies additionally included investigations of whether species traits might help explain missed occurrences. For instance, Milberg et al. (2008) tested the effect of plant mean height and life form on missed occurrences but found no significant relationship. One reason for this finding might be that seedlings or juvenile individuals with low abundances, are particularly prone to being overlooked, but traits retrieved from databases usually refer to adult plants.

Similar to the findings of Dennett and Nielsen (2018), who reported no differences in pseudoturnover across life forms (including graminoids), we found no differences when comparing graminoids vs non-graminoids. In addition, Dennett and Nielsen (2018) detected only a weak effect of horizontal and total vegetation cover on pseudoturnover, which supports our findings of a non-significant relationship between pseudoturnover and vegetation cover. However, this result is in contrast to that of Vittoz and Guisan (2007), who found significantly higher pseudoturnover in plots with dense vegetation than in plots with open vegetation, indicating that species are easier to detect in open vegetation and that high vegetation coverage might be a source of error and should not be neglected in future studies.

In accordance with the results reported by Morrison et al. (2020), who found no effect of species richness on pseudoturnover, our linear mixed-effects model indicated only a non-significant relationship between species richness and pseudoturnover. Nevertheless, the differences in pseudoturnover among habitat types indicated in our linear mixed-effects model, might at least partly be explained by the combined effect of species richness tending to differ and the percentage of overlooked taxa differing among habitat types, with highest values in dry grasslands and the lowest in raised bogs (Figure 5). These factors might contribute to variation in pseudoturnover and should be considered more closely in future work.

4.3 | Pseudoturnover effects on ecological inference

In our study, mean ecological indicator values were mostly robust against inter-observer differences. Notably, this was true for cover-weighted and -unweighted mean indicator values. Cover-weighted mean indicator values account for dominant species that likely better reflect the ecological conditions of a site and therefore are preferred when the goal is studying environmental differences among sites (e.g. Boch et al., 2021). In contrast, cover-unweighted means rather overestimate the influence of low-cover species, which may be growing outside their ecological optimum. Thus, as low-cover species are more likely to be overlooked, cover-unweighted mean indicator values are even more sensitive to observer differences than cover-weighted means. Our findings of non-significant relationships when comparing unweighted mean indicator values between the two observers suggest that mean indicator values are also relatively robust against differences in cover estimates. Our findings are in line with those of Futschik et al. (2020), who assessed inter-observer errors using plots on mountains in Austria and Slovakia and found that a thermal vegetation indicator, i.e. a cover-weighted value comparable to the mean indicator value for temperature used in the present study, was relatively weakly affected by observer differences. These authors therefore concluded that such indicators can be used to reliably estimate vegetation changes when studying the effects of climate change on vegetation.

4.4 | Implications for long-term monitoring programs and the analysis of resurvey data

Long-term vegetation monitoring programs often include basic measures to keep observer errors consistently low, such as employing experienced observers, providing continuous training opportunities (e.g. identification and field courses, excursions), facilitating ongoing professional exchange between observers, and avoiding systematic spatial, temporal and syntaxonomic observer biases by using all observers at different times of the survey period and in different habitat types and biogeographic regions. As an additional measure, we propose the double-surveying of plots on a regular basis to monitor the magnitude of inter-observer error.

While the actual change in vegetation composition in terms of species turnover usually exceeds the magnitude of observer-driven pseudoturnover in studies where historical plots sampled more than 10 years ago are resurveyed (Burg et al., 2015; Futschik et al., 2020), in shorter-term studies and in monitoring programs pseudoturnover should be seen as a serious issue and be minimized. In this study, we observed that the magnitude of pseudoturnover can be strongly reduced by simple stepwise species-list aggregation. When analyzing resurvey data, we therefore suggest conducting such aggregation steps prior to analysis to minimize and equalize inter-observer errors. However, as no information on the conservation status is usually available for species aggregates (e.g. Bilz et al., 2011; FOEN, 2011; Bornand et al., 2016), this method largely precludes deeper analysis of changes in particular taxonomic groups, such as threatened or national priority species. The identification to the lowest possible taxonomic level delivers information on the occurrence and distribution of particular taxa, which is important, e.g. for revising Red Lists of threatened species. Thus, in contrast to the common procedure in many monitoring programs, we propose that species aggregates should not be defined a priori and recommend instead the identification of taxa to the lowest level possible, only applying aggregation later, before the analyses.

Another important finding is that the commonly used mean indicator values are robust to inter-observer differences in species lists. They thus can provide a reliable estimate of temporal vegetation and ecological changes, and at the same time help to minimize pseudoturnover in monitoring programs.

AUTHOR CONTRIBUTIONS

Ariel Bergamini and Rolf Holderegger conceived the monitoring program. Ariel Bergamini, Helen Küchler, Meinrad Küchler and Steffen Boch developed the initial concept of this study. Angéline Bedolla, Ariel Bergamini, Helen Küchler, Meinrad Küchler, Steffen Boch, Tobias Moser and Ulrich H. Graf gathered field data. Angéline Bedolla, Klaus T. Ecker and Ulrich H. Graf compiled the data. Helen Küchler, Meinrad Küchler and Steffen Boch analyzed the data. Steffen Boch wrote the first draft of the manuscript. All authors commented on the manuscript and contributed to the final version.

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DATA AVAILABILITY STATEMENT

Primary data are available via EnviDat (http://doi.org/10.16904/envidat.317).

ORCID

Steffen Boch https://orcid.org/0000-0003-2814-5343
Helen Küchler https://orcid.org/0000-0003-1060-9808
Meinrad Küchler https://orcid.org/0000-0002-3340-6838
Angéline Bedolla https://orcid.org/0000-0001-5562-0643
Klaus T. Ecker https://orcid.org/0000-0003-3388-1353
Rolf Holderegger https://orcid.org/0000-0001-7062-1759
Ariel Bergamini https://orcid.org/0000-0001-8816-1420

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1. Number of double-surveyed plots per year for all plots and separately for each habitat type

Appendix S2. Number of sampling years of each of the 19 observers, showing little turnover of observers over time with a relatively constant core team present in most of the years

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