

1 Observer and relocation errors matter in 2 resurveys of historical vegetation plots 3

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15 **Running headline:** errors in resurveys of historical vegetation plots

16

17 Abstract

18

- 19 1. **Aim:** Revisits of non-permanent, relocatable plots first surveyed several decades ago offer a direct
20 way to observe vegetation change and form a unique and increasingly used source of information
21 for global change research. Despite the important insights that can be obtained from resurveying
22 these quasi-permanent vegetation plots, their use is prone to both observer and relocation errors.
23 Studying the combined effects of both error types is important since they will play out together in
24 practice and it is yet unknown to what extent observed vegetation changes are influenced by these
25 errors.
- 26 2. **Methods:** We designed a study that mimicked all steps in a resurvey study and that allowed to
27 determine the magnitude of observer errors only versus the joint observer and relocation errors.
28 Communities of vascular plants growing in the understorey of temperate forests was selected as
29 study system. Ten regions in Europe were covered to explore generality across contexts and fifty
30 observers were involved, which deliberately differed in their experience to make vegetation records.
- 31 3. **Results:** The mean geographical distance between plots in the observer+relocation error dataset was
32 24 m. The mean relative difference in species richness in the observer error and the
33 observer+relocation dataset was 15% and 21%, respectively. The mean 'pseudoturnover' between
34 the five records at a quasi-permanent plot location was on average 0.21 and 0.35 for the observer
35 error and observer+relocation error datasets, respectively. More detailed analyses of the

36 compositional variation showed that the nestedness and turnover component were of equal
37 importance in the observer dataset, whereas turnover was much more important than nestedness
38 in the observer+relocation dataset. Interestingly, the differences between the observer and the
39 observer+relocation datasets largely disappeared when looking at temporal change: both the
40 changes in species richness and species composition over time were very similar in these datasets.

41 4. **Conclusions:** Our results demonstrate that observer and relocation errors are non-negligible when
42 resurveying quasi-permanent plots. A careful interpretation of the results of resurvey studies is
43 warranted, especially when changes are assessed based on a low number of plots. We conclude by
44 listing measures that should be taken to maximally increase the precision and the strength of the
45 inferences drawn from vegetation resurveys.

46

47 **Key-words:** legacy studies, nestedness, pseudoturnover, species richness, temperate forest, true turnover,
48 understorey vegetation.

49

50 Introduction

51 The diversity and composition of plant communities have changed dramatically over the last decades
52 (Vellend et al. 2017). Therefore, there is a large interest among scientists, managers, and policy makers to
53 document and understand these changes in vegetation over time. Among the methods to study temporal
54 changes in plant diversity, revisits of plots surveyed in the past offer a direct way to observe change (e.g.
55 Vellend et al. 2013a; Chytrý et al. 2014; Kapfer et al. 2017). Indeed, many vegetation plots have been first
56 recorded multiple decades ago, i.e. in many places before the onset of major environmental changes, and
57 therefore these legacy data form a unique source of information for global change research (Verheyen et al.
58 2017). Compiling and maximally exploiting the available historical data on plant communities is therefore an
59 important research priority for vegetation science.

60 The number of vegetation resurvey studies is steadily increasing, indicating that the scientific community
61 embraced this challenge (Hédli et al. 2017). Recent examples of studies that resurvey legacy data are found
62 across various ecosystems, ranging from mountain tops (Wipf et al. 2013), over forests (Naaf & Kolk 2016),
63 moorlands (Britton et al. 2017), and hedgerows (Litza & Diekmann 2017), to prairies (Alstad et al. 2016) and
64 grasslands (Gillet et al. 2016; Stevens et al. 2016). Besides these single region and single system studies, more
65 and more multi-region and/or multi-system studies are emerging (e.g. De Frenne et al. 2013; Bernhardt-
66 Römermann et al. 2015). Combining resurveys allows to check for the generality of community change (e.g.
67 Vellend et al. 2013b) and helps to better understand the relative importance of, and interactions between,
68 the different drivers of change (Verheyen et al. 2017). These combined resurvey studies can complement
69 community monitoring networks, such as National Forest Inventory-programmes or country-level surveys,
70 which generally cover shorter time periods, but have more solid designs ensuring representativeness and
71 statistical robustness.

72 Despite the important insights that can be obtained from resurveying historical vegetation plots, the
73 approach is prone to several types of errors (Kapfer et al. 2017). Two important error types are observer and
74 relocation errors. The first type of errors, observer errors, arise because the initial surveys and recent
75 resurveys are typically done by different surveyors and, when comparing across resurvey datasets of multiple
76 regions, surveyors usually also differ. This type of uncertainty has been well studied (e.g. Kirby et al. 1986;

77 Lepš & Hadincová 1992; Vittoz & Guisan 2007; Archaux 2009). In a recent review, Morrison (2016) found that
78 the percentage of species detected by one observer but not by others (a phenomenon coined
79 'pseudoturnover' by Nilsson & Nilsson 1985), is typically anywhere between 10 and 30%. Burg et al. (2015)
80 benchmarked pseudoturnover due to observer error against turnover over time on Alpine mountain summits
81 and found that the observer-related pseudoturnover was almost three times smaller than the actual changes
82 observed over one century (13.6% and 41.4%, respectively), confirming the presence of true floristic changes
83 over time.

84 Relocation errors, on the other hand, are caused by the imperfect relocation of the historical plots in the
85 field. The majority of resurvey studies, and especially those working with plots first established many decades
86 ago, work with so-called quasi-permanent plots (*sensu* Kapfer et al. 2017, also referred to as semi-permanent
87 plots). Quasi-permanent plots are plots that were never permanently marked in the field (e.g. by means of
88 paint markings on trees or metal poles inserted in the soil). Hence, only the approximate plot location is
89 known, e.g. via descriptions, sketched maps or markings on topographic maps. Relatively few studies have
90 attempted to quantify the inaccuracies introduced by imperfect relocation (Fischer & Stöcklin 1997; Ross et
91 al. 2010; Kopecký & Macek 2015). Kopecký & Macek (2015) compared long-term vegetation changes in
92 permanent versus quasi-permanent plots in the same region of the Czech Republic. They found similar
93 temporal changes in multivariate plot composition in both plot types and concluded that resurveys are
94 apparently robust against relocation errors. Fischer & Stöcklin (1997) and Ross et al. (2010) came to a similar
95 conclusion by comparing the present-day spatial turnover in the vegetation composition with the turnover
96 over time. They assessed the spatial turnover by recording multiple vegetation plots at varying distances
97 from the likely location of the historical vegetation plot.

98 Here we quantify the contribution of observer and relocation errors in resurvey studies across multiple
99 regions in Europe. As outlined above, observing temporal changes in the vegetation seem to be robust
100 against the individual types of errors, but it is unknown whether this conclusion still holds when both types
101 of uncertainty are combined and when looking across multiple resurvey data sets. This is of crucial
102 importance, because in most resurvey projects both errors will play out together. Therefore, we designed a
103 study that mimicked all steps in a typical resurvey study and that allowed to determine the magnitude of

104 observer errors only versus joint observer and relocation errors. Vascular plants growing the understorey of
105 temperate forests were selected as the focal community, given the rapidly growing number of resurvey
106 studies that have been performed in this system over the past few years (see Verheyen et al. 2017). The study
107 covered ten regions across Europe to explore generality across contexts (e.g. quality historical data, forest
108 types) and involved no less than fifty observers, which deliberately differed in their experience to make
109 vegetation records (from students to experienced botanists). The latter is important since the level of training
110 is known to vary strongly between resurvey projects and can have an important impact on the (re)survey
111 outcome (e.g. Seidling et al. 2014). The following research aims were addressed:

- 112 (i) Quantify the differences in geographical location, species richness, and species composition
113 between the records made by different surveyors in independently relocated plots (observer +
114 relocation error) and compare with differences due to observer error only (not for geographic
115 location);
- 116 (ii) Determine the degree to which the between-record variation in geographic location, species
117 richness, and species composition can be explained by surveyor experience;
- 118 (iii) Explore the impact of the observer and relocation error on inferences about the changes in
119 species richness and community composition over time.

120 Material and Methods

121 *Study design and data collection*

122 To closely mimic the procedure that is usually adopted when performing resurveys of quasi-permanent plots,
123 we followed the following steps: identify suitable legacy data, select plots, gather a team of surveyors, and
124 perform the field measurements. First, suitable datasets were selected that met the following criteria:

- 125 - Plots are located in a single forest or landscape in the temperate forest zone in Europe (further
126 referred to as a region);
- 127 - Given the interest in documenting long-term vegetation changes, the plots were first surveyed at
128 least two decades ago;
- 129 - The first survey was done by an experienced botanist to minimize the chances of species' overlooking
130 and misidentification in the historical data;

- 131 - The original survey methods (e.g. survey date, plot shape and size, definition of vegetation layers,
132 nomenclature) are well documented;
- 133 - The plots are quasi-permanent, that is, they have not been permanently marked so that relocation
134 relies on field notes, maps, and/or canopy descriptions.

135 We selected ten legacy data sets from different regions throughout Europe covering a range of forest types
136 and contexts (Table 1). The dates of the first surveys ranged from 1930-1936 up to 1995 and plot sizes varied
137 between 25 m² and 400-600 m².

138 In the second step, five plots were randomly picked from each of the selected data sets, provided that no
139 major disturbances, such as canopy removal or soil disturbance, had taken place in the plot locations since
140 the time of the first sampling. This criterion allows benchmarking our error estimations with minimal
141 vegetation change scenarios: if the obtained error estimates are significantly smaller than the observed
142 temporal vegetation changes in the absence of a major disturbance, then we are confident to pick up real
143 changes in more disturbed conditions as well.

144 Third, a team of five surveyors with different levels of vegetation survey experience was formed in each of
145 the ten regions. We distinguished three levels: junior surveyors have surveyed less than 100 plots throughout
146 their career, intermediates have surveyed between 100 and 500 plots, and seniors have surveyed more than
147 500 plots. Each region had at least one person per experience category in its team. In total 20 senior, 17
148 intermediate, and 13 junior surveyors were involved. As expected, the level of experience and the age of the
149 surveyors was positively correlated ($r_{\text{Spearman}} = 0.48$ with $p < 0.001$ and $n = 50$).

150 In the fourth step, each team performed the resurvey. The actual field campaign consisted of three stages
151 (see Fig. 1 for a schematic representation):

- 152 - *Plot location* – Using the available historical information (Table 1: ‘Location info’), each team member
153 individually relocated the most likely plot centre. To do so, the team travelled together to an
154 unequivocal landmark (e.g. a crossroad or a bridge over a small stream) and from there one team
155 member after the other went into the forest to search for the most probable location of the plot
156 centre. This location was discretely marked. With all five team members relocating a historical

157 record, this resulted in five 'plot realisations' of the same quasi-permanent plot. Finally, all team
158 members returned to the location they marked and the pairwise geographic distances between all
159 the centres of the five plot realisations were measured.

160 - *Observer+relocation error* – The team members then established a plot at 'their' location and made
161 a vegetation survey, by recording the presence of all vascular understorey plant species. The
162 definition of 'understorey' varied somewhat between regions because the definition of the original
163 survey was used. In most cases, the understorey was defined as all vascular plants – woody and non-
164 woody – below 1.5m height.

165 - *Observer error* – Finally, one of the five plot realisations was randomly picked and the four other
166 team members repeated the vegetation description for that location. These records thus differ only
167 because of observer error.

168 This protocol ultimately resulted in two data sets: an observer+relocation error data set covering ten regions
169 and an observer error data set covering nine regions (the French team did not perform the observer error-
170 only surveys). Note that the observer error may involve several types of uncertainties. In our field protocol,
171 all species' identifications were doublechecked by the senior surveyor(s) and no cover estimates were
172 performed. This means we opted to focus on overlooking error only, and not on misidentification nor (cover)
173 estimation errors (sensu Morrison 2016), since overlooking errors are considered to be the most important
174 source of error (Archaux 2009). All resurveys were performed in spring or summer 2016, based on the period
175 of the initial survey.

176 *Data analysis*

177 To address our first research aim, we quantified the differences in geographic location, species richness, and
178 species composition between the vegetation records of each quasi-permanent plot. For the
179 observer+relocation error data set, this means we looked at the variation between the five records made by
180 the different surveyor at 'their' plot location (i.e., alternative plot realisations). For the observer error data
181 set, we quantified the variation between the records of the different surveyors recording the same plot
182 location; the difference in geographical location was thus zero. We used pairwise metrics to quantify the
183 differences among all ten possible combinations of the five records within each quasi-permanent plot.

184 *Geographic location*: we simply used the pairwise distances (in metres) between the records that were
185 measured in the field (only relevant for the observer+relocation error data set). *Species richness*: we worked
186 with a relative difference in species richness $|S_i - S_j|/\max(S_i, S_j)$, with S_i and S_j the numbers of species in
187 records i and j , respectively ($i \neq j$). *Species composition*: we used a pairwise dissimilarity metric $(S_i + S_j -$
188 $2J)/(S_i + S_j)$, with J the number of species that occur in both compared records. This dissimilarity is known
189 as the Sørensen dissimilarity and has been generally used in studies on observer error to quantify what is
190 commonly called ‘pseudoturnover’ (Morrison 2016). We note that the term turnover is misleading here,
191 because this metric also quantifies nestedness patterns derived from richness differences, in addition to pure
192 turnover (Baselga 2010). After calculating the pairwise differences among records (richness, composition,
193 and the natural logarithm of geographical distance), their variation was modelled with multilevel models of
194 the form $y_i = \mu + region_{j[i]} + plot_{k[i]} + \varepsilon_i$ (model 1). Here μ was the grand mean for the between-record
195 differences in richness, composition and geographical distance within quasi-permanent plots. The group-
196 level effects *region* ($j = 1, \dots, 10$) and quasi-permanent *plot* ($k = 1, \dots, 50$) accounted for the clustering of
197 records within these groups and were assumed to come from separate independent zero-mean normal
198 distributions, e.g., $plot_k \sim N(0, \sigma_{plot}^2)$. The residual errors were assumed to be drawn from $\varepsilon_i \sim N(0, \sigma^2)$.
199 Models were fitted with the probabilistic programming language Stan, called from R 3.4.0 through the *brms*
200 package (Bürkner, in press, R Core Team 2017). We used the default priors for these multilevel models, that
201 is, a zero-mean normal distribution with standard deviation of one or, for the variance parameters, a Student-
202 t distribution with sigma = 10 and 3 degrees of freedom. We ran four chains of thousand iterations each,
203 after a warmup of thousand iterations.

204 A recent review study on observer error (Morrison 2016) listed the mean Sørensen dissimilarities (\pm standard
205 deviation) reported in seventeen published studies across different vegetation types. We took the
206 opportunity to directly compare the compositional differences in the present study to the results reported
207 in those previous studies. Therefore, we performed a formal meta-analysis on the Morrison data, using a
208 multilevel meta-analytic model $z_j = \mu + u_j + m_j$ (model 2; ‘random effects’ meta-analysis). Here z_j was the
209 mean dissimilarity for the j th study ($j = 1, \dots, 17$), μ the meta-analytic mean, u_j the study-specific effect that

210 was normally distributed around zero with between-study variance σ_u^2 , and m_j the sampling error effect for
211 each study, which is also normally distributed around zero with the corresponding sampling error variance
212 σ_j^2 reported in the review (Nakagawa & Santos 2012). The model was fitted again with Stan, using the same
213 settings as above.

214 Our second aim was to determine whether the between-record variation in geographic location, species
215 richness, and species composition was explained by surveyor experience (junior, intermediate, senior). The
216 same base model of the first analysis was used (model 1), but the grand mean μ was replaced by another
217 linear predictor. *Geographic location*: for the pairwise geographic distance between records, we replaced the
218 grand mean with a predictor 'surveyor combination'. The six levels of this predictor were defined by the
219 experience of the surveyors that made the compared records, e.g., 'junior – intermediate' for a distance
220 between records made by a junior and intermediate surveyor. *Species richness*: the number of species in a
221 record was modelled with an intercept for each of the three surveyor experience levels. Since plot sizes
222 differed somewhat between regions, we also added a slope for the plot size, which was normalized to
223 average to zero, so that intercepts were fitted for average-sized plots. Plot size was not log-transformed here,
224 because richness increased in rather linear way with size (plot sizes were relatively small and probably in the
225 first part of a species-area curve) (Fig. S1). Besides the group-level effects for region and plot, we added an
226 additional effect for surveyor identity to account for the multiple records made by the same person. *Species*
227 *composition*: we first decomposed each pairwise Sørensen dissimilarity (cf. first analysis) into its two additive
228 components: a pure turnover term and a term quantifying nestedness due to richness differences (Baselga
229 2010). Then, the pairwise dissimilarities (turnover, nestedness) between the records were modelled by the
230 predictor 'surveyor combination' (see analysis geographic location). For the observer+relocation error data
231 set, the geographic distance between the records was added as a predictor, because records made in plot
232 realisations that were further apart may involve larger compositional differences. The models were fitted
233 again with Stan, using the same settings as above.

234 The third aim was to explore how the observer and relocation errors may influence the inferences about
235 temporal changes in species richness and community composition. Here we used the same approach as in

236 the first analysis, but making pairwise comparisons of records over time instead of across space. First, for
237 each quasi-permanent plot, we calculated the pairwise relative difference in species richness and the
238 Sørensen dissimilarity between the vegetation record of the initial survey (legacy data set) and each of the
239 five resurvey of the present study. The pairwise differences were modelled with model 1 again, first on the
240 entire data set and then on the subsets of data including junior-only or senior-only data. These subsets allow
241 exploring how surveyor experience influences inferences about the temporal changes in vegetation.

242 Results

243 The mean geographical distance between plots in the observer+relocation error dataset was 24 m (95% CI =
244 [15.3 – 36.0]) (Fig. 2). Differences between regions were significant, ranging from a mean distance of 10 m in
245 the Flemish Ardennes (BE) up to 45 m in the Pol'ana Mts. area (SK) (Fig. S2).

246 The mean relative difference in species richness in the observer error dataset was 15% (Fig. 2 and Fig. S2).
247 With a mean species richness estimate for an average-sized plot (*ca.* 260 m²) of 36 species, a 15% difference
248 corresponds to the recording of \pm six species. The mean relative difference in species richness in the
249 observer+relocation dataset was higher (21%), although the 95% credible interval overlapped with the
250 observer error-only interval. The mean difference in species composition between the five records at a quasi-
251 permanent plot location (Sørensen dissimilarity), was on average 0.21 and 0.35 for the observer error and
252 observer+relocation error datasets, respectively (Fig. 2 and Fig. S2). The relocation error clearly leads to
253 additional compositional variation between records compared to the observer error only. Interestingly, the
254 mean dissimilarity found in our observer error-only dataset corresponded very well to a meta-analytic mean
255 dissimilarity of 0.18 reported in the recent literature (Fig. 2).

256 More detailed analyses of the geographic distance between the plot locations in the observer+relocation error data set
257 showed no effect of surveyor experience (Fig. 3). The between-record variation in species richness, however,
258 showed that juniors found significantly less species compared with seniors and intermediates when only
259 observer error was involved; surveyors with intermediate or senior experience did not differ here. When
260 both observer and relocation error were involved, less experienced surveyors (junior and intermediate)
261 found significantly lower richness values compared with more experienced colleagues (second column Fig.

262 3). Compositional variation between records was largely due to some species replacing others across the
263 records (turnover > nestedness component), so a surveyor who found species that others did not find and
264 *vice versa*. This was especially true for the observer+relocation error data set, with clearly higher turnover
265 values compared with the observer error-only dataset (third column Fig. 3). Surveyor type did not, however,
266 explain the turnover degree between records. The degree to which records showed nestedness patterns (last
267 column Fig. 3) was somewhat related to observer type, consistent with the differences in species richness.
268 The largest values were found for records made by juniors versus seniors or intermediates, partly because
269 juniors simply missed a number of species creating nestedness patterns across the records. The mean
270 dissimilarity due to nestedness was comparable between the two datasets. The geographic distance between
271 the plot locations did not explain compositional dissimilarity (turnover and nestedness) in the
272 observer+relocation error data set. Together, results on the compositional variation showed that the
273 nestedness and turnover component were of equal importance in the observer dataset, whereas turnover
274 was much more important than nestedness in the observer+relocation dataset.

275 Interestingly, the differences between the observer and the observer+relocation datasets largely
276 disappeared when looking at temporal change: both the changes in species richness and species composition
277 over time were very similar in these datasets (Fig. 4). The mean change in species richness across regions was
278 centred around zero, but in some regions the trend for junior surveyors deviated from the general trend. As
279 junior surveyors tended to find less species (Fig. 3), they found a smaller mean increase in species richness in
280 regions where richness tended to increase in time, and a larger mean decrease in richness in regions with
281 overall decreasing richness (Fig. 4 top row). The mean temporal change in composition in both datasets was
282 high: 0.51 (95% CI = [0.44 – 0.59]; observer error) and 0.50 (95% CI = [0.43 – 0.57]; observer+relocation error).
283 In two regions ((Sogn og Fjordane (NO) and Nyírség (HU)) the compositional change over time was clearly
284 higher for the plots recorded by the junior surveyors, especially in the observer+relocation dataset.

285

286 Discussion

287 We were able to quantify and disentangle the observer and relocation errors when resurveying quasi-
288 permanent vegetation plots. A large number of observers were involved in the present study, covering ten
289 temperate forest regions, with different plot sizes, initial survey dates and original plot descriptions. Hence,
290 our results likely represent the range of errors that can be encountered in these systems. Below, we discuss
291 the main findings using our research questions as the backbone. We conclude with recommendations for
292 future resurvey studies.

293 *Quasi-permanent plots cannot be perfectly relocated*

294 Our results demonstrate that surveyors hardly ever located the plots to be resurveyed on the same spot
295 (pairwise distance <5 m in only 8% of the cases); generally distances amounted up to several tens of meters.
296 Kopecký & Macek (2015) reported a mean distance of 27 m between database stored coordinates and tree
297 markings of permanent plots in the Czech Republic. This is in line with the mean pairwise plot distance of 24
298 m observed in our study. The large variation in pairwise distances among relocated plots between the ten
299 study regions (Fig. S2) was most likely due to differences in forest characteristics and the quality of the
300 descriptions of the historical plots. Relocation is, for instance, more difficult in large forests with a low density
301 of unequivocally retrievable landmarks such as crossroads, bridges, etc. and in forests with little variability in
302 topography and canopy composition. Ambiguous and imprecise descriptions of the original plot location will
303 obviously render the plot relocation more difficult. Given the importance of the relocation error we found
304 here, resurvey projects should preferably be initiated only when high quality historical information is
305 available.

306 *Observer and relocation error lead to significant errors in the estimation of species richness 307 and composition*

308 The differences in richness estimates (15%) between observers were very comparable to the 19.2% reported
309 by Archaux (2009). The more since the latter authors also included bryophytes in their survey, which are
310 generally more easily overlooked. We should stress, though, that our protocol only focused on overlooking
311 errors and eliminated identification errors as much as possible. Although the latter error is deemed to be
312 relatively small (e.g. 5.3% at the species level according to Archaux, 2009), our error estimates have to be
313 interpreted as minimal errors that can be encountered. The estimated observer error-only on composition

314 (21%) was also very similar to the mean compositional variation reported in the literature (Morrison 2016).
315 The imperfect relocation of the plots added additional variability to the richness and, especially, composition
316 assessments, with error estimates of 21% and 35%, respectively. This is not surprising as the relocated plots
317 were often several tens of meters apart (Fig. 2 & Fig. S2). Indeed, it has been shown that large compositional
318 changes can occur at this scale. For instance, Vanhellemont et al. (2014) reported mean herb layer
319 dissimilarity values of c. 0.8 between 10 m x 10 m plots laid out in two one ha zones in two contrasting forest
320 types in Belgium. In their study, the nestedness and turnover components accounted for 0.2 and 0.6 of the
321 dissimilarity, respectively. Hence, inferences about temporal changes in species richness and composition in
322 individual plots should be interpreted with care as differences smaller than c. 25% and c. 40%, respectively,
323 could simply result from observer and relocation errors (cf. Morrison 2016). Directional changes in
324 community properties, such as changes in species richness, could still be detected when a sufficiently large
325 number of plots are combined. The 21% error on species richness estimates would mean that at least ~25
326 survey-resurvey plot-pairs are needed to detect a 20% difference in species richness at $\alpha=0.05$ and with a
327 power of 0.90 (Neter et al. 1990: 1152). The high degree of uncertainty associated with estimates of (changes
328 in) species richness probably helps to explain why meta-analyses of temporal changes in vegetation richness
329 and diversity often did not find a net change over time (Verheyen et al. 2012; Vellend et al. 2013b; Bernhardt-
330 Römermann et al. 2015). (Dis-)similarity-based metrics of community composition change are non-
331 directional and increasing the number of plots will not help to increase the signal-to-noise ratio. Hence, other
332 approaches may be needed as discussed below.

333 *The expertise of the surveyor matters*

334 In line with the majority of earlier studies (for an overview, see Morrison 2016), we observed an
335 underperformance of surveyors with little experience, expressed as the number of vegetation plots recorded
336 in their career. Junior surveyors found on average five species less than more experienced researchers (Fig.
337 2), which was also reflected in the nestedness of their records within the more species rich records of the
338 other surveyors. The vegetation turnover component in the observer error only dataset was, however, of the
339 same order of magnitude than the nestedness component, indicating that to some extent also different
340 species are seen by the observers. Interestingly, surveyor experience did not help to explain variation in the

341 turnover component in the observer+relocation dataset, confirming that the dissimilarity between the plots
342 in this dataset is to a large extent caused by the spatial turnover in composition present in the vegetation.
343 Based on our experience with resurvey studies in forests (Verheyen et al. 2017), it became clear that resurvey
344 projects are often performed by unexperienced researchers, such as MSc-students. The results presented
345 here clearly show that supervisors of such projects should pay a lot of attention to good training. This would
346 avoid elevated estimation errors and even biased outcomes, as suggested by the analysis of temporal
347 changes in species richness depicted in the top row of Fig. 4. Involving more experienced surveyors and using
348 multiple observers per plot have been recommended as strategies to reduce the observer error (e.g. Archaux
349 2009; Morrison 2016). However, note that the spatial turnover in composition due to relocation error, which
350 is responsible for a large part of the dissimilarity between records, will not be affected by these measures.

351 *Interpreting temporal changes in richness and composition should be done with care*

352 The similar temporal changes in richness and composition in the observer error only and the
353 observer+relocation error datasets is not surprising when considering that both datasets actually involve
354 relocation error when comparing with an old vegetation plot. Indeed, looking across time, the location of the
355 plot used for the observer error only is not necessarily closer to the exact location of the historical record.
356 The results depicted in Fig. 4 allowed us to confirm temporal changes in richness in only two out of ten
357 regions, which is at least partly due to the errors associated with richness estimates and the too low number
358 of plots used as discussed above. By contrast, true compositional changes over time were more common,
359 with an overall mean compositional dissimilarity of c. 50% (i.e. well above the 40% threshold value mentioned
360 above). The latter is in line with Burg et al. (2015) who found three times higher compositional dissimilarity
361 over time than between observers and concluded that temporal changes reflected a true ecological pattern.
362 Large changes in composition, exceeding 40% are indeed often observed (see e.g. Verheyen et al. (2012) for
363 a synthesis of 23 resurvey datasets of temperate forest understorey vegetation), meaning that true
364 compositional changes will have happened in most resurveys studies. However, the unknown accuracy of
365 resurveys and the low precision of the obtained estimates of taxon-based compound community descriptors
366 plea for a different approach to analysing resurvey data. Lumping data in metrics such as species richness
367 and community (dis)similarity removes all species-level information and masks important directional changes

368 in individual species or species groups. Recent quantitative developments such as model-based approaches
369 in community ecology now allow quantifying changes in community composition directly from the data that
370 were observed, that is, the changes in species presences or abundances (Warton et al. 2015; Ovaskainen et
371 al. 2017). Specifically in the context of resurvey studies, we recently developed an approach that looks for
372 species-level effects of time period to construct a multiple-site metric that quantifies the degree to which
373 individual species responses are consistent and result in directional changes in community composition
374 (Baeten et al. 2014). The unknown accuracy and low precision of the taxon-based methods also call for more
375 mechanistic, hypothesis-driven research in this field. *A priori* identifying the potential drivers of change in
376 combination with Ellenberg-indicator values (Diekmann 2003) and/or a trait-based approach, e.g. via the
377 response-and-effect framework (Suding et al. 2008), to translate driver impacts into expected patterns of
378 functional composition changes will enable to robustly quantify directional changes over time. Recent
379 examples of such species-oriented and trait-based approaches are Ash et al. (2017) and Li & Waller (2017),
380 respectively.

381 *Conclusions*

382 Our results demonstrate that observer and relocation errors are non-negligible when resurveying quasi-
383 permanent plots. A careful interpretation of the results of resurvey studies is warranted, especially when
384 changes in richness are assessed based on a low number of plots (e.g. less than several dozens). Whereas the
385 low precision of the obtained estimates of community change is to some extent unavoidable in this type of
386 studies, we argue that the following measures should be taken to maximally increase the precision and the
387 strength of the inferences that can be drawn:

- 388 - Only perform a resurvey study when the quality of the original plot descriptions is sufficiently high
389 to relocate and resurvey the plots;
- 390 - Perform resurvey studies with well-trained surveyors or with teams of surveyors to minimize the
391 observer error;
- 392 - Quantify and report the observer and the relocation error in every study by applying the protocol
393 proposed here in a subset of the resurveyed plots;

- 394 - Significant directional changes in community properties, such as species richness, will only surface
395 when several dozens of plots can be resurveyed, given the high error associated with the estimation
396 of these properties;
- 397 - Consider alternatives to compound (dis-)similarity-based descriptions of community change, such as
398 methods that quantify changes in individual species and hypothesis-driven trait-based approaches.

399 Some of these recommendations have been proposed before (e.g. Vellend et al. 2013a; Chytrý et al. 2014;
400 Kapfer et al. 2017; Morrison 2016), but in this paper we provide a protocol to actually quantify the errors.
401 Adopting these recommendations will increase the reliability of the inferences that can be drawn from future
402 resurvey projects. To conclude, we emphasise that people should certainly not be discouraged by the results
403 presented here. Vegetation records going back multiple decades are an invaluable resource for global change
404 research (cf. Verheyen et al. 2017) and researchers should try to get the most out of it to better understand
405 past and predict future biodiversity changes.

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417 Author's contributions

418 KV and LB designed the study and led the data analysis and the writing of the manuscript. All other authors
419 helped with the data collection, extensively commented on earlier versions of the paper and gave final
420 approval for publication.

421 Supporting Information and Appendices

422 **Appendix S1.** Relationship between plot size and species richness

423 **Appendix S2.** Interregional variation in the between-record differences in location, richness, and
424 composition

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527

529 **Table 1** Overview of the study regions (ranked alphabetically), the plot characteristics and the composition
 530 of the survey teams.

| Region (N, E) | Country | Forest type* | Year first survey | Plot-size (m ²) | Location info \$ | Resurvey team £ |
|-------------------------------------|---------|-------------------------------------------------------------------|----------------------|--------------------------------|------------------|-----------------------------------------------|
| Białowieża (52°44', 23°52') | PL | FAG-03 <i>Carpinetalia betuli</i> P. Fukarek 1968 | 1949 | 100 | M/D/C | S (52) / S (28) / I (49) / J (38) / J (34) |
| Brandenburg (52°34', 13°00') | DE | FAG-03 <i>Carpinetalia betuli</i> P. Fukarek 1968 | 1964-1970 | 400 | M/C | S (56) / S (52) / I (37) / I (33) / J (23) |
| Czech Karst (49°54', 14°07') | CZ | FAG-03 <i>Carpinetalia betuli</i> P. Fukarek 1968 | 1974 | 400 | M/D/C | S (40) / S (34) / I (32) / I (30) / J (29) |
| Flemish Ardennes (50°55', 3°43') | BE | POP-02 <i>Alno- Fraxinetalia excelsioris</i> Passarge 1968 | 1980 | 100-200 | M/C | S (47) / I (42) / I (33) / J (32) / J (28) |
| Nyírség (47°46', 22°16') | HU | POP-02 <i>Alno- Fraxinetalia excelsioris</i> Passarge 1968 | 1930-1936 | 25 | M/D/C | S (55) / S (28) / I (58) / I (28) / J (29) |
| Pálava (48°53', 16°39') | CZ | FAG-03 <i>Carpinetalia betuli</i> P. Fukarek 1968 | 1953-1963 | 400-600 | M/D/C | S (39) / S (31) / I (44) / I (30) / J (22) |
| Poľana Mts. (48°37', 19°21') | SK | FAG-03 <i>Carpinetalia betuli</i> P. Fukarek 1968 | 1964 | 500 | M/D/C | S (47) / S (41) / I (36) / J (36) / J (29) |
| Sogn og Fjordane (61°46', 5°56') | NO | FAG-05 <i>Aceretalia pseudoplatani</i> Moor 1976 | 1979-1980 | 25 | D/C | S (55) / S (48) / I (36) / I (34) / J (38) |
| Sudetes (51°01', 6°44') | PL | PUB-01 <i>Quercetalia pubescenti-petraeae</i> Klika 1933 | 1990-1992 | 200 | M/C | S (50) / S (45) / S (33) / I (29) / J (28) |
| Thiérache # (49°45', 3°57') | FR | FAG-03 <i>Carpinetalia betuli</i> P. Fukarek 1968 | 1995 | 200-500 | M/C | S (45) / S (28) / I (39) / I (34) / J (34) |

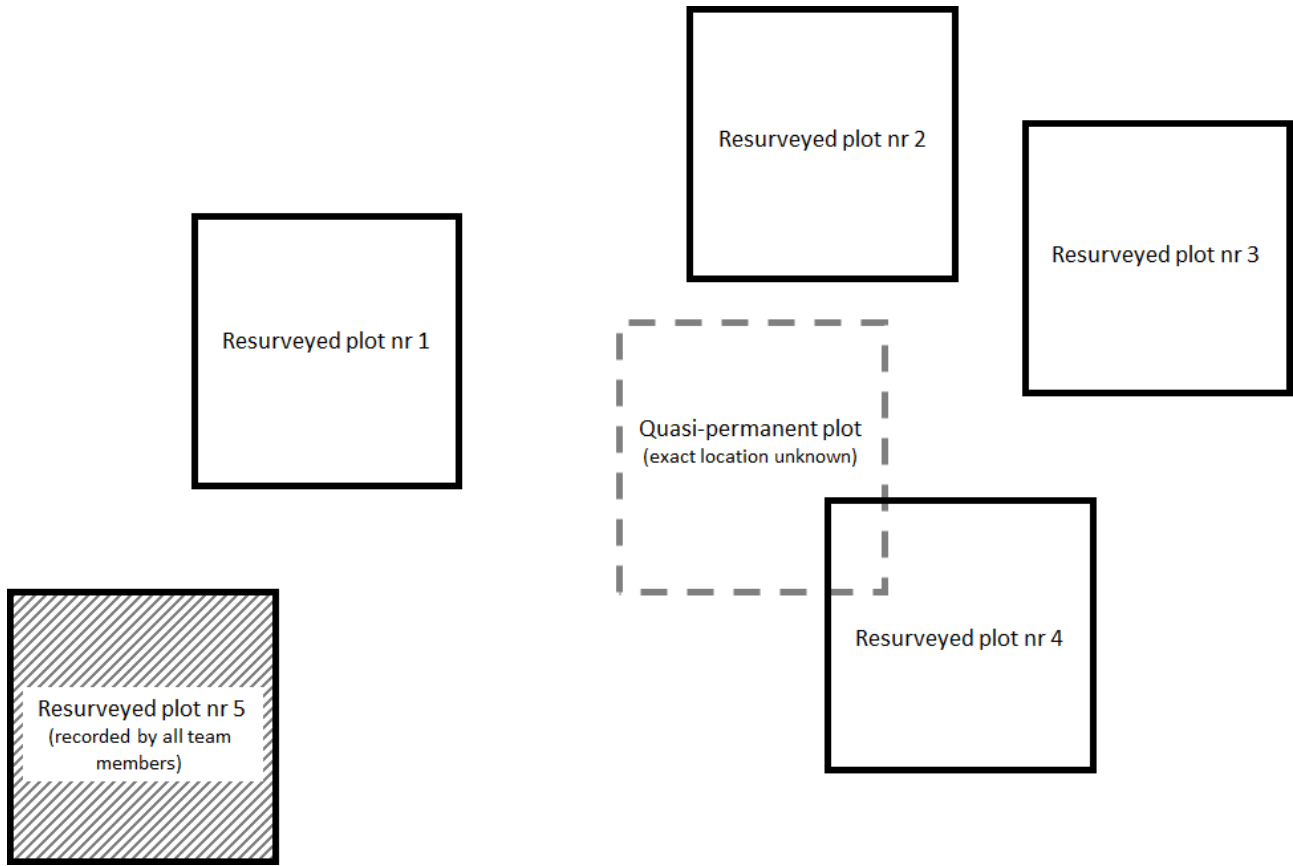
531 * Order-level classification according to Mucina et al. (2016);

532 \$: Available information to relocate the plot; M: Map; D: Written descriptions; C: Canopy data recorded at
533 the time of the first survey;

534 £: S: Senior; I: Intermediate; J: Junior. Surveyor age in 2016 is indicated between brackets.

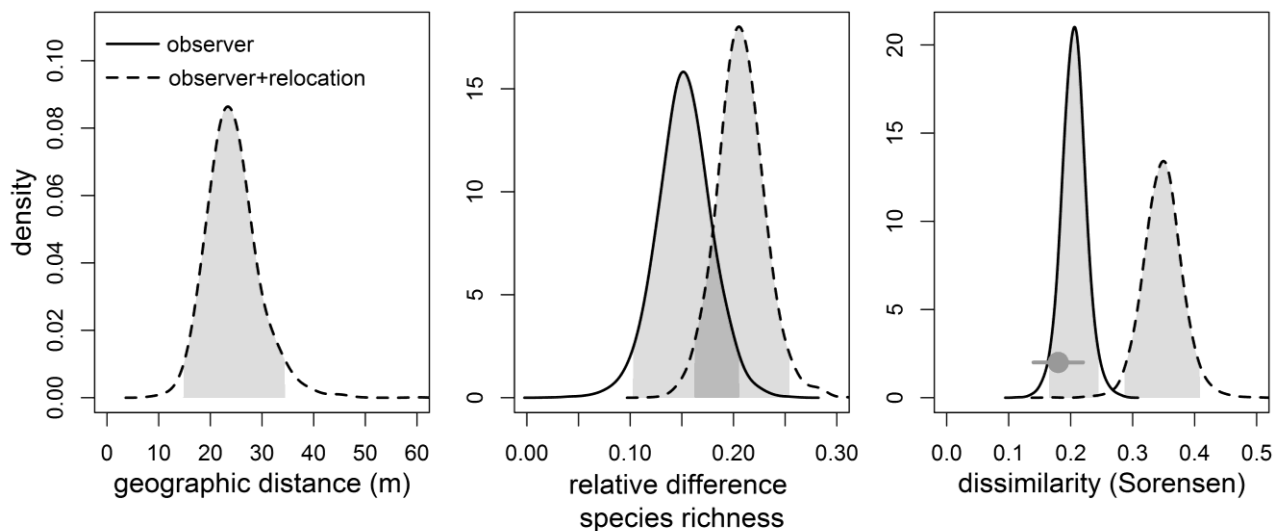
535 #: The observer error-only dataset is not available for this region

536



538

539 **Fig. 1** Schematic representation of the sampling procedure. The quasi-permanent plot (with unknown exact
540 location) was relocated and resurveyed by each of the five survey team members in a best possible way (plot
541 'realisations' nr. 1 – 5). These records involve observer+relocation error. Then, one of the five plot realisations
542 was randomly selected and the four other team members repeated the vegetation description for that plot
543 (nr 5 in this example) to determine the observer error only.



544

545 **Fig. 2** Mean pairwise differences in geographic location (left), species richness (mid), and species composition (right)

546 between the vegetation records within quasi-permanent plots. Two data sets were analysed separately: one involving

547 observer error only (different surveyors sampling the same plot location) and one involving both observer and relocation

548 error (different surveyors sampling an individually relocated plot). Results show the posterior distribution of the mean

549 of the pairwise differences within quasi-permanent plots, with the 95% highest posterior density intervals shaded in

550 grey. The geographic distance is simply the distance in meters between the locations of the records and is only relevant

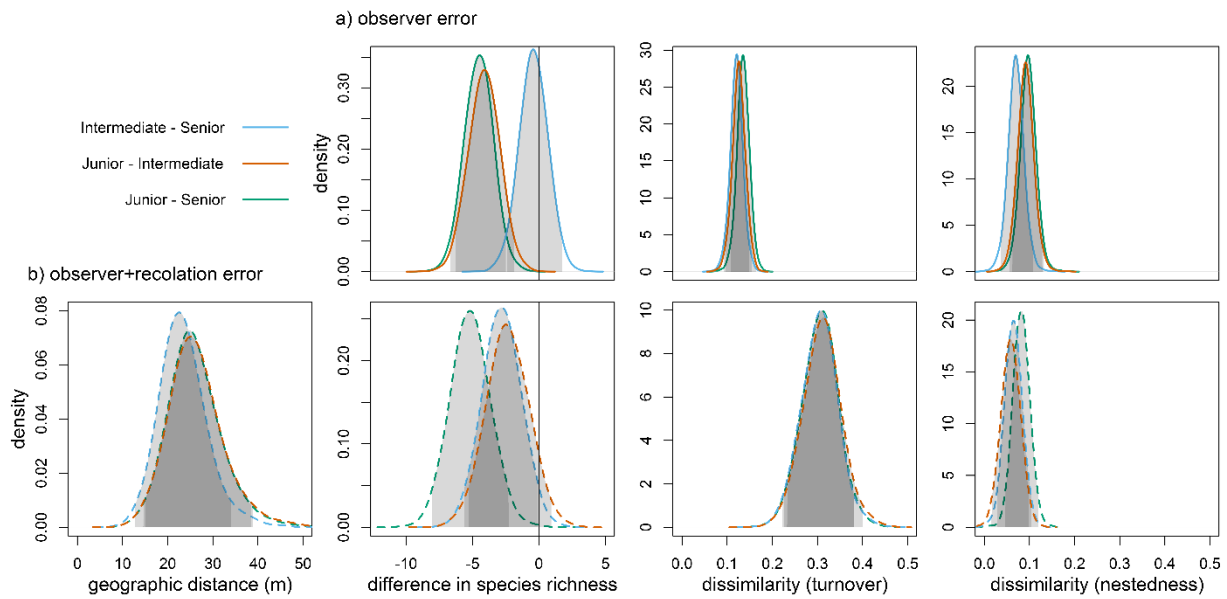
551 for the observer+relocation error data set. The relative difference in species richness between records was scaled by

552 the maximum richness of the records. The compositional difference was calculated as a pairwise Sørensen dissimilarity.

553 The right panel also shows the result of a meta-analysis on the compositional dissimilarity across seventeen published

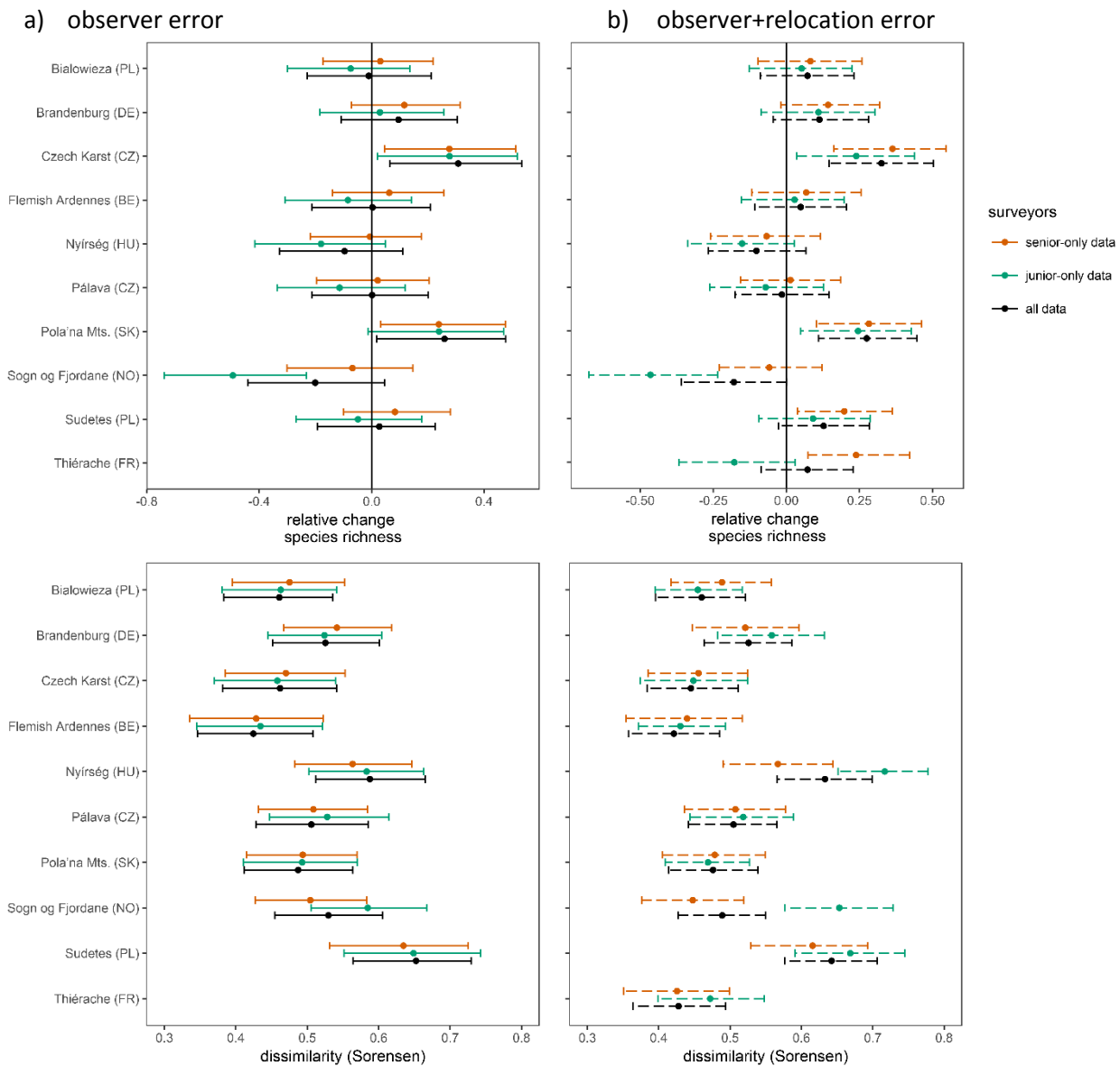
554 observer error studies (Morrison, 2016): meta-analytic mean compositional dissimilarity across observers with 95 %

555 intervals as grey horizontal error bars.



556

557 **Fig. 3** Mean pairwise differences in geographic location, species richness, and species composition between the
 558 vegetation records of surveyors with different level of experience. Two datasets were analysed separately: observer
 559 error (top row) and observer+relocation error (bottom row). Differences between three surveyor combinations are
 560 shown, excluding comparisons within a level of experience (e.g., mean difference in richness between the records of
 561 two junior surveyors). Results show the posterior distribution of the mean of the pairwise differences within quasi-
 562 permanent plots, with the 95 % highest posterior density intervals shaded in grey. Geographic distance is the distance
 563 in meters between the locations of the records and is only relevant for the observer+relocation error data set. The mean
 564 difference in species richness is given for an average-sized plot and was calculated so that negative values imply higher
 565 species richness in the records made by the more experienced surveyor (e.g., junior – senior). Two components of
 566 compositional dissimilarity are shown: replacements of some species by others (turnover) and richness differences
 567 between surveyors creating nestedness patterns across their records (nestedness).



569 **Fig. 4** Mean temporal change in species richness (top row) and species composition (bottom row) in ten European
 570 regions. In each region, five quasi-permanent plots were selected from a legacy data set and resurveyed by five different
 571 observers recording either one relocated plot location (observer error; left column) or five individually relocated plot
 572 locations (observer+relocation error; right column) (see Fig. 1). Results show the mean change and 95 % credible interval
 573 in richness or composition within quasi-permanent plots over time. The relative difference in species richness between
 574 the initial vegetation record (legacy data set) and a rerecording of the same quasi-permanent plot (current study) was
 575 scaled by the maximum richness of the two records, while the change in composition expressed as a pairwise Sørensen
 576 dissimilarity. In each region, resurveys were made by five different surveyors and the graphs show the result using the
 577 data from all surveyors, or the subsets of data including only the senior or the junior surveyors. The regions are ranked
 578 alphabetically.