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10

11 **How much would it cost to monitor farmland biodiversity in Europe?**

12

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52

53 **Running title: Farmland biodiversity monitoring scenarios**

54

55 **Summary**

- 56 1. To evaluate progress on political biodiversity objectives, biodiversity monitoring provides  
57 information on whether intended results are being achieved. Despite scientific proof that  
58 monitoring and evaluation increase the (cost) efficiency of policy measures, cost estimates for  
59 monitoring schemes are seldom available, hampering their inclusion in policy programme  
60 budgets.
- 61 2. Empirical data, collected in twelve case studies across Europe, were used in a power analysis to  
62 estimate the number of farms that would need to be sampled per major farm type to detect  
63 changes in species richness over time for four taxa (vascular plants, earthworms, spiders and  
64 bees). A sampling design was developed to allocate spatially, across Europe, the farms that  
65 should be sampled.
- 66 3. Cost estimates are provided for nine monitoring scenarios with differing robustness for detecting  
67 temporal changes in species numbers. These cost estimates are compared to the Common  
68 Agricultural Policy (CAP) budget (2014–2020) to determine the budget allocation required for the  
69 proposed farmland biodiversity monitoring.
- 70 4. Results show that the bee indicator requires the highest number of farms to be sampled and the  
71 vascular plant indicator the lowest. The costs for the nine farmland biodiversity monitoring  
72 scenarios corresponded to 0.01%–0.74% of the total CAP budget and to 0.04%–2.48% of the CAP  
73 budget specifically allocated to environmental targets.
- 74 5. *Synthesis and applications.* The results of the cost scenarios demonstrate that, based on the taxa  
75 and methods used in this study, a Europe-wide farmland biodiversity monitoring scheme would  
76 require a modest share of the Common Agricultural Policy budget. The monitoring scenarios are  
77 flexible and can be adapted or complemented with alternative data collection options (e.g. at  
78 national scale or voluntary efforts), data mobilization, data integration or modelling efforts.

79

80 **Key-words:** agriculture, agri-environment schemes, biodiversity indicator, common agricultural  
81 policy, empirical data, farming system, habitat, sampling design, species trend, power analysis.

## 82 **Introduction**

83 Numerous scientific papers and research projects address the global biodiversity decline (Butchart *et*  
84 *al.* 2010). In response, political initiatives to reverse declines in biodiversity have increased in number  
85 and in their global coverage, e.g. the Aichi Biodiversity targets (CBD 2010) and the establishment of  
86 the Intergovernmental Platform on Biodiversity & Ecosystem Services (IPBES). The EU 2020 target of  
87 biodiversity enhancement in European agricultural areas was adopted in the greening of the  
88 European Common Agricultural Policy (CAP) for the period 2014–2020 (EU Regulation No  
89 1307/2013). Positive effects of policies and adopted measures on biodiversity both at farm and  
90 landscape scales are, however, equivocal (Kleijn *et al.* 2011; Lindenmayer *et al.* 2012) and it is  
91 generally acknowledged that current monitoring of agri-environment schemes needs to be improved  
92 (Pullin *et al.* 2009; Scheper *et al.* 2013). Biodiversity monitoring is required to inform on possible  
93 positive or negative side-effects of management practices, external drivers (e.g. climate change), and  
94 of other policy measures such as the European renewable Energy Directive (EC 2009/28).

95 Europe is far from void of biodiversity monitoring schemes, but many operate at a national scale due  
96 to governance, language and institutional reasons (e.g. the UK Countryside Survey  
97 [<http://www.countrysidesurvey.org.uk>] or the National Inventory of Landscapes in Sweden [NILS  
98 [Ståhl *et al.* 2011]). Pan-European monitoring schemes do exist but are much more rare, such as the  
99 European Land Use and Cover Area Frame Survey (LUCAS) which does not focus on biodiversity  
100 (EUROSTAT 2009). There are also citizen-science monitoring networks that provide excellent pan-  
101 European biodiversity data which are increasingly used in policy reporting, such as the Pan-European  
102 Common Bird Monitoring Scheme (<http://www.ebcc.info/pecbm.html>) and the European butterfly  
103 monitoring (Brereton, Van Swaay & Van Strien 2009). Whereas standardization of the sampling and  
104 data processing protocols within existing monitoring schemes can be well organized, the  
105 interoperability of indicators and data hamper the type of assessments that can be performed with  
106 data across monitoring schemes (Henry *et al.* 2008), making biodiversity assessments across taxa,  
107 countries and farming types currently precarious. To improve the interoperability of data and  
108 indicators, standardization and the implementation of a shared sampling design are considered  
109 crucial (Schmeller *et al.* 2015).

110

111 Biodiversity monitoring is often regarded as costly making budget constraints a common reason to  
112 avoid its implementation (Caughlan & Oakley 2001). However, Naidoo *et al.* (2006) showed that the  
113 effectiveness of policies is positively correlated with the presence of monitoring efforts. If decision  
114 makers are earnest in their concerns for biodiversity, biodiversity monitoring at multinational scale  
115 should be an integral part of the monitoring and reporting criteria of a European policy instrument  
116 like the CAP. The actual implementation of a shared farmland monitoring scheme would not only

117 strengthen informed decision making, but it would also demonstrate political willingness to act,  
118 counteracting existing doubts on the current approach of the greening of the CAP (Péer *et al.* 2014).  
119 The need and willingness to invest in biodiversity information has been expressed at global and  
120 European level (Council of the European Union 2010), but a specific level of monitoring expenditure  
121 is not defined. Rieder (2011) argues that between 0.5 and 10% of a policy instrument budget should  
122 be allocated to evaluation and monitoring, whereas recommendations of the European Commission  
123 are at the lower end of this range (0.5%, EC 2004). Whilst cost estimates for the recording of some  
124 individual biodiversity indicators exist at regional or national level (see e.g. Mandelik, Roll & Leischer  
125 2010), this information is lacking at international scales.

126  
127 The objective of this paper is to stimulate the development, the discussion and eventually the  
128 implementation of a European farmland biodiversity monitoring system by proposing a sampling  
129 design to detect changes in species richness in four taxonomic groups (vascular plants, earthworms,  
130 spiders and bees). Measures of agro-environmental schemes are aimed and implemented on  
131 individual farms. Therefore, the farm was considered to be the relevant scale for monitoring changes  
132 in farmland biodiversity. As specific measures often target specific farm types, a distinction in major  
133 farm types was used.

134 Combining information from a pan-European data set on the variability of species richness for four  
135 taxa across major farm types and the spatial distribution of farm types in Europe, enabled an  
136 estimation of the number of farms that would need to be sampled to detect changes in species  
137 richness. The proposed sampling design for a European farmland biodiversity monitoring scheme is  
138 complemented with estimates of the related costs presented in Targetti *et al.* (2014), which were  
139 then compared with the CAP budget (2014–2020) to estimate a possible budget allocation for the  
140 monitoring scheme. To the best knowledge of the authors, this is the first attempt to provide cost  
141 estimates for large-scale monitoring for European policy instruments, using statistical estimates of  
142 the number of farms that should be sampled to reliably detect changes in biodiversity.

143

## 144 **Materials and methods**

### 145 *Method outline*

146 This study aimed to develop a monitoring scheme in which a 10% change in species richness in 5  
147 years could be identified with a 10% probability error for farmland biodiversity per dominant farm  
148 type per region in Europe. To achieve this, the study combined results from four different  
149 components. First, we obtained an estimate for the number of farms that should be sampled per  
150 region in Europe, by applying a power analysis on empirical data of species richness of four taxa for  
151 12 case studies. Second, we delineated regions in Europe based on the country boundaries,

152 environmental conditions and farm composition. Third, we applied the farm sample size estimates to  
153 all regions of Europe with different indicator set options. Fourth, we computed the costs for these  
154 monitoring scenarios and compared them to the CAP budget (2014–2020).

155 The four steps are explained in brief hereafter, a more detailed explanation of methods and  
156 uncertainties can be found in Appendix S1 in Supporting Information.

157

#### 158 *Source of empirical data*

159 In 12 European case studies (i.e. specific farm type in one region), 10–20 farms were sampled. These  
160 case studies were part of the BioBio project (Fig. 1, full project description in Herzog *et al.* 2012).

161

162 Within each case study region, farms were randomly selected. For the purpose of this paper, the  
163 farm types (*sensu* EC 1985) were aggregated into four categories, namely (i) field crops and  
164 horticulture, (ii) specialist grazing livestock, (iii) mixed crops and livestock and (iv) permanent crops.

165 Farms were sampled using an indicator set which was developed with stakeholders and includes  
166 minimal information redundancy (Herzog *et al.* 2012, ch. 2). The indicator set contained 23 indicators  
167 spanning four categories: genetic, species and habitat diversity and farm management, of which the  
168 species category included sampling of four taxa: vascular plants (from here on referred to as plants),  
169 earthworms, spiders and bees (Herzog *et al.* 2013). Farmer interviews and habitat mapping were  
170 done for all the land managed by the farmer. Per farm, each habitat type was randomly sampled  
171 once for all of the four taxa on the same location. Vegetation samples (10 m × 1 m in linear and 10 m  
172 × 10 m in areal habitats) consisted of recording all plant species and allocating cover estimates at 5%  
173 precision. Earthworms were sampled via extraction for 10 minutes with an expellant solution (diluted  
174 allyl isothiocyanate: AITC) and then hand sorted for 20 minutes. Three subsamples were taken (30  
175 cm x 30 cm x 20 cm deep) during one visit. Spiders were suction-sampled from soil surface and  
176 vegetation using a modified leaf blower (Stihl SH 86-D). On three different days, five areas of 35.7 cm  
177 diameter were sampled within each selected habitat. Bees were sampled during good weather  
178 conditions with a handheld net along a 100 m × 2 m transect for 15 min. Bees were sampled on three  
179 different days. A more detailed description of the standardized sampling protocols can be found in  
180 Dennis *et al.* (2012).

181 Species richness was computed per taxa per farm (Fig. 2). Means and standard deviations of the  
182 observed species richness were computed using species rarefaction-extrapolation curves (Chao *et al.*  
183 2014). An example of the variation in species richness within a case study region is shown in Figure 3.  
184 Species accumulation curves for all case studies and all four taxa are presented in Appendix S1.

185

#### 186 *Budgetary cost calculations and estimates*

187 The costs and the number of hours spent preparing fieldwork, collecting data and processing field  
 188 samples (i.e. taxonomic sorting and identification) were recorded and used to compute the average  
 189 efforts required for sampling a standardized farm (Targetti *et al.* 2014). The costs of monitoring farms  
 190 throughout Europe were estimated using labour cost differences between European countries  
 191 (Targetti *et al.* 2012). The estimation of the total budget required per sampled farm considered five  
 192 different components: data collection, supervision, data processing and reporting, data quality  
 193 assurance and administration (Busch & Trexler 2003). The quantification method for each  
 194 component can be found in Appendix S2.

195

196 *Required number of farms that need to be sampled*

197 Based on the variability of the empirical data for the four taxa, estimates could be made of the  
 198 number of farms required to be sampled to detect statistically significant trends in species richness  
 199 per major farm type: the required farm sample size.

200 Required farm sample sizes were computed for detecting a change in the average species richness  
 201 for each of the four taxa between two consecutive sampling rounds. The variance of the estimated  
 202 average difference  $V(\bar{d})$  in species richness between two sampling rounds is given by the summed  
 203 variances of estimated average species richness found in each sampling round minus their covariance  
 204 (Brus & Noij 2008):

205

206 
$$V(\bar{d}) = Var(\bar{y}_2 - \bar{y}_1) = Var(\bar{y}_1) + Var(\bar{y}_2) - Covar(\bar{y}_2, \bar{y}_1) \quad \text{eqn. 1}$$

207 The variance of the estimated average species richness ( $Var(\bar{y}_1)$  and  $Var(\bar{y}_2)$  in equation 1) is  
 208 determined by the variation of the species richness per farm in the sampled population of farms, the  
 209 sample size (number of observed sampling units [farms]) and the type of sampling design (e.g. simple  
 210 random or stratified random). Since farms were selected fully randomly within case study regions,  
 211 the variance of the estimated average species richness in sampling round 1, can simply be estimated  
 212 by:

213

214 
$$Var(\bar{y}_1) = \frac{S_1^2}{n} \quad \text{eqn. 2}$$

215 With  $S_1^2$  being the population variance of the species richness per farm in sampling round 1, and  $n$   
 216 the sample size (number of observed farms per sampling round). Using the means and standard  
 217 deviations of species richness per farm, derived from the rarefaction procedure, 1000 random sets of

218 species richness for each farm were drawn from a normal distribution. For each set, the population  
219 variance per case study region was computed.

220 The covariance of the two estimated averages (third term in Equation 1) depends on the correlation  
221 of the species richness per farm in the two sampling rounds and the proportion of farms that is  
222 revisited and observed at both times, referred to hereafter as the matching proportion. The stronger  
223 the correlation and the larger the matching proportion, the larger the covariance and the smaller the  
224 variance of the estimated change in average species richness. For simple random sampling, the  
225 covariance of the estimated average species richness in the two sampling rounds equals (Brus & Noij  
226 2008):

$$227 \text{Covar}(\bar{y}_2 - \bar{y}_1) = \frac{S_{1,2}^2 \cdot p}{n} = \frac{r_{1,2} \cdot S_1 \cdot S_2 \cdot p}{n} \quad \text{eqn. 3}$$

228 With  $S_{1,2}^2$  being the population covariance of the species richness per farm in sampling round 1 and 2,  
229  $p$  the matching proportion, and  $r_{1,2}$  the correlation of the species richness per farm in sampling round  
230 1 and 2. The population standard deviations in two sampling rounds  $S_1$  and  $S_2$  were assumed to be  
231 equal. The matching proportion was assumed to be 80% and the correlation between the first and  
232 the second sampling round,  $r_{1,2}$ , was estimated to 0.9 for plants and 0.75 for the three invertebrate  
233 groups based on empirical time series of species richness of previous projects (Aviron *et al.* 2009;  
234 M.W. Lüthi, unpublished results). Since these values are based on relatively few data, an uncertainty  
235 bandwidth of 0.1 was assumed. This was incorporated by drawing, for each of the 1000 random sets  
236 of species richness, a temporal correlation from a uniform distribution of 0.85–0.95 for plants and  
237 0.7–0.8 for the invertebrates.

238 Finally, the following requirements on the quality of the statistical tests were defined: the probability  
239 of wrongly identifying a 10% change in the total number of species should be smaller than 10% (type  
240 I error); the probability of not identifying an actual change of 10% of the average species richness  
241 should also be smaller than 10% (type II error). Given these requirements, the sample sizes can be  
242 computed by a power analysis (Brus & Noij, 2008) with a 95% confidence interval that includes the  
243 uncertainty of the original species richness data and the uncertainty bandwidth of the temporal  
244 correlation. The power analysis is based on two key equations (Brus & Noij 2008; Brus *et al.* 2011),  
245 one to compute the critical value for the difference  $\bar{d}$  beyond which the null-hypothesis  $H_0 \bar{d}=0$  is  
246 rejected (i.e. there is a 10% change in species richness):

$$247 \quad 248 \quad d_{\text{crit}} = \Phi^{-1}(1 - \alpha/2; 0; V(\bar{d})) \quad \text{eqn. 4}$$

249  
250 And a second one to compute the power of the test (required to be above 90%):

251

252  $1 - \beta = \Phi(d_{\text{crit}}; \bar{d}; V(\bar{d}))$  eqn. 5

253

254 Here  $\alpha$  refers to the type I error,  $\beta$  to the type II error.  $\Phi^{-1}(1 - \alpha/2; 0; V(\bar{d}))$  (equation 4) is the  
255 quantile corresponding with a cumulative lower probability of  $1 - \alpha/2$  for a normal distribution with  
256 mean 0 and variance  $V(\bar{d})$ .  $\Phi(d_{\text{crit}}; \bar{d}; V(\bar{d}))$  (equation 5) is the cumulative lower probability of  
257  $d_{\text{crit}}$  for a normal distribution with mean  $\bar{d}$  and variance  $V(\bar{d})$ .

258

### 259 *Sampling design at European level*

260 To allow for stratified sampling of dominant farm types, 25 countries in Europe were divided in  
261 homogeneous regions (Fig. 1) (Jongman *et al.* 2012). Region delineation was determined by the farm  
262 types (according to the Farm Accountancy Data Network, FADN), country boundaries, and the  
263 environmental zone (Metzger *et al.* 2005). The spatial units used were the European Nomenclature  
264 of Territorial Units for Statistics level 2 (NUTS2). FADN farm types were ranked based on their  
265 surface. Country boundaries were used to take into account national differences in the agro-  
266 environmental schemes. Each NUTS2 region was described by one to four dominant farm types  
267 (based on a cover of at least 75% of the total utilized agricultural area). Per country, comparable  
268 NUTS2 regions were merged while respecting boundaries determined by different environmental  
269 zones. A maximum of five regions per country was set to avoid having too many small regions  
270 (Jongman *et al.* 2012). The composition of dominant farm types per region can be found in Appendix  
271 S3.

272 The smallest reporting unit for monitoring was the “Farm type per region” with the required number  
273 of farms to be sampled being expressed as the percentage of the total number of farms per farm  
274 type per region. In compliance with existing recommendations (Elbersen *et al.* 2010), a minimum  
275 sample size of 15 farms per farm type per region was retained.

276 Percentages of the total number of farms of that farm type per region could only be derived for the  
277 nine case study regions for which FADN data was available on the regional farm composition, namely  
278 Austria, France, Germany, Hungary, Italy, the Netherlands, Spain (Dehesa), Spain (olives) and Wales.

279 A five-yearly frequency of monitoring (sampling interval) was assumed following the  
280 recommendation of the European Biodiversity Observation Network project (Brus *et al.* 2011).  
281 According to the temporal sensitivity of the Essential Biodiversity Variables (Pereira *et al.* 2013), this  
282 frequency is in line with the dynamics of important biodiversity variables such as «Species  
283 distribution», «Ecosystem structure» and «Community composition». Instead of sampling all farms

284 once per five years, each year, 20% of the farms would be sampled over a five year period to ensure  
285 a continuous stream of data, to allow for a more resource-efficient approach and to reduce the  
286 effect of annual climate variability.

287

### 288 *Indicator scenarios*

289 Nine scenarios were developed to allow for comparison between different options for information  
290 output based on three different indicator sets and on three levels of biodiversity data robustness  
291 (Fig. 4). The scenarios were applied to all identified regions in Europe. This implies the underlying  
292 assumption that the sampled farms were on average representative for all of Europe and ignores  
293 regional variability in species richness across Europe. This crude assumption was necessary because  
294 no other data sets were available to allow for a more sophisticated extrapolation method. For more  
295 reflection on the impact of this assumption see Appendix S1.

296

297 [Include Figure 4 here]

298

299 There are three scenarios to consider: a full indicator set, a full indicator set without bees and a  
300 reduced indicator set (only plants). For each indicator set, three additional scenario options were  
301 developed using the estimates of the required farm sample size per species indicator per farm type.  
302 For the High, Average and Low scenario options, respectively, the highest, the average and the  
303 lowest sample size percentage of all four taxa per farm type were applied. Whereas the High  
304 scenario option offers a first estimation for an effective monitoring scheme, the Low scenario reflects  
305 a case in which minimal monitoring is organized at European level. It is assumed that countries will  
306 then develop complementary monitoring at national or regional level.

307 The combination of options leads to nine cost scenarios for a European farmland biodiversity  
308 monitoring scheme with different percentages of farms of a farm type that should be sampled per  
309 region and with different information outputs.

310

### 311 *Comparison of cost scenarios with the CAP budget*

312 To compute cost estimates, the required farm sample sizes of the scenarios were multiplied by the  
313 monitoring costs for a standardized farm for each country (Table S2.2 in Appendix S2). The computed  
314 costs were placed into the context of the budget allocated to environmental and biodiversity  
315 objectives of the CAP for 2014–2020.

316 The total CAP budget for First and Second Pillar measures is 408 billion Euro for the period of 2014–  
317 2020. The “green” budget, which are the funds allocated for environmental and biodiversity targets,

318 makes up 30% of the total budget (the “greening” package of Pillar 1 and earmarked budget of Pillar  
319 2 [Péer *et al.* 2014]). The total “green” budget was estimated at 122.5 billion Euro for the whole  
320 period with an indicative annual budget of 17.5 billion Euro.

321

## 322 **Results**

323 The estimated number of farms that should be sampled for the detection of a 10% change in species  
324 richness per farm type over a five year period differed between case studies and between farm types  
325 from 19 to 465 farms. In general, monitoring bees required the largest, and monitoring plants the  
326 smallest number of farms to be sampled. On average the Permanent Crops farm type required the  
327 largest farm sample sizes (Table 1).

328

329 The required farm sample size in the High scenarios mostly followed the percentage of farms that  
330 should be sampled for the bee and plant indicators respectively (Table 2). Only in the case of the  
331 High scenario for Specialist grazing livestock, the earthworms showed the highest variability,  
332 requiring a higher number of farms to be sampled for a representative and reliable estimate.

333

334 Depending on the scenario chosen, approximately 184k (High scenario, full indicator set), 38k  
335 (Medium scenario, full indicator set exclusive bees) and 5.6k (Low scenario, reduced indicator set)  
336 farms would need to be sampled, which corresponds to 6.3%, 1.3% and 0.2% respectively of the total  
337 number of European farms. The difference between the full set with and without bees for High and  
338 Low scenarios is 77k and 15k farms, respectively.

339 An implementation of the full indicator set for the High scenario, would require 0.74% of the CAP  
340 budget and 2.48% of the “green” CAP budget (443 Mio € annually) (Table 3). Not monitoring the bees  
341 would reduce the costs considerably (a cost reduction of 79-126 Mio € per year), namely to 0.53% of  
342 the CAP budget and to 1.75% of the “green” CAP budget. The reduced indicator set for the Low  
343 scenario would require 0.01% of the total CAP budget and 0.04% of the “green” CAP budget (7 Mio €  
344 annually).

345

346 In general, the estimated CAP budget allocation in seven of the nine scenarios remained below the  
347 lowest budget allocations proposed in the literature (i.e. the European Commission proposed 0.5%  
348 [2004]). When considering the “green” CAP budget, five of the nine scenarios fulfilled this criterion.

349

## 350 **Discussion**

351 The results provide an informed estimate of the required sampling design, sample size and costs for  
352 farmland biodiversity monitoring for Europe. Depending on the scenario chosen, between 6.3% and

353 0.2% of the total number of European farms would need to be sampled, which would require  
354 between 0.74% and 0.01% of the CAP budget (Table 3). Of the three fauna indicators, the bees  
355 demonstrated the highest data variability and therefore required the largest farm sample size.  
356 Estimates are contingent on several assumptions and simplifications which do not necessarily cover  
357 the expected complexity of reality. The proposed sampling design is not presented as the ideal  
358 monitoring scheme, but rather as a starting point for discussions and further refinements. For this  
359 purpose, the estimates are presented at the regional scale (Appendix S1), to provide input for the  
360 development of or to complement existing monitoring schemes at national or regional scales.

361

### 362 *Validity of the results*

363 The first important methodological limitation is that the estimates of the required farm sample sizes  
364 are based on species data from only four taxa, which serve as proxies for the numerous other species  
365 depending on European farmland. The choice of plants, earthworms, spiders and bees as farmland  
366 biodiversity indicators was based on scientific robustness, iterative stakeholder consultations and  
367 feasibility (Herzog *et al.* 2013). These criteria increase the potential acceptance and implementation  
368 of the indicator set (Danielsen *et al.* 2010). Future monitoring could increase the number of taxa  
369 included or invest in data integration between existing monitoring schemes to increase the  
370 sensitivity for specific changes in agricultural management practices (Henry *et al.* 2008).

371 A second limitation is that the data used were gathered using a single sampling approach whereas  
372 the sampling techniques could be revised to reduce data variability (for bees see e.g. Fortel *et al.*,  
373 2014). Additionally, the proposed monitoring scheme uses the farm as a monitoring unit to focus on  
374 the scale at which agricultural management decisions are taken. For many biodiversity and  
375 ecosystem service estimates, the inclusion of information on larger-scale processes requires also  
376 monitoring at a landscape scale (Geijzendorffer & Roche 2013; Schneider *et al.* 2014). The cost  
377 estimates indicate that even if additional monitoring efforts at landscape scale doubled monitoring  
378 costs, six out of the nine scenarios would still remain below the 0.5% boundary of the total CAP  
379 budget.

380 The third important limitation is that the empirical data base stems from only twelve case studies,  
381 collected in one year. For the extrapolation, the variability of species diversity was assumed to be  
382 similar per farm type throughout Europe. As a consequence of the small empirical data base in  
383 comparison to the total number of farms in Europe, the estimated farm sample sizes should be  
384 considered as coarse rather than precise indications, and monitoring cost estimates should be  
385 treated with caution. Still, the existence of an empirical data base – albeit small – is a major asset to  
386 evaluate the effort needed to implement a monitoring scheme. The presented findings should be

387 considered as a starting point for the urgently needed debate on the feasibility of a European  
388 biodiversity monitoring scheme (Council of European Union 2010).

389

### 390 *Monitoring scenarios*

391 The full indicator set (four taxa, habitat and farm management indicators, including genetic diversity)  
392 was developed based on minimum information overlap in the BioBio project. It covers five of the six  
393 Essential Biodiversity Variables (EBV) classes (Pereira *et al.* 2013), namely Genetic Composition,  
394 Species Populations, Community Composition, Ecosystem Function and Ecosystem Structure. This  
395 indicates good overall coverage of farmland biodiversity, in comparison to the reporting for the  
396 Habitat Directives which covers 3 EBV classes (Geijzendorffer *et al.*, 2015). The proposed monitoring  
397 scheme was developed to capture broad biodiversity trends to assess the influence of large scale  
398 changes such as adaptations of European policies like the CAP reform. With 0.74% of the CAP budget  
399 (2.48% of the budget allocated to “green targets”), information about the biodiversity status on 6.3%  
400 of all farms in Europe could be obtained (the High scenario and full indicator set option).

401 The proposed farm sample sizes would allow to detect a 10% change in species richness per farm  
402 type per region over five years, which is a rather crude in comparison to the annual change of 1%  
403 required for the monitoring of red list species and threatened habitats according to the European  
404 Habitats Directive (EC 2005). However, whereas the red list monitoring focuses on the monitoring of  
405 individual species, the presented sampling design aims to detect large changes in species richness  
406 per taxa across many different habitat types on farmland under dynamic farm management practices  
407 per region and the 10% change in species richness should therefore be considered as a starting point  
408 rather than an aim per se. Although this study focused on species richness, as a sole indicator for  
409 trends in biodiversity it is obviously limited and further work such as on the EBVs (Schmeller *et al.*  
410 2015) could identify other indicators of importance for farmland biodiversity. Some of these  
411 indicators, involving e.g. species identity, could already be quantified from the data gathered with  
412 this monitoring protocol, others might require complementary data and/or monitoring. According to  
413 the results, the 10% error probability is only achieved for all four taxa under the High scenario. The  
414 required farm sample size estimates could be further adjusted by taking into account regional  
415 species pool patterns, by adjusting for the spatial biodiversity patterns within Europe (e.g.  
416 earthworm distribution patterns [Entling *et al.* 2012]) or by including alternative sampling methods.  
417 Ideally the proposed monitoring scheme would not be implemented standalone, but serve as a  
418 backbone for the integration of data from existing monitoring scheme to further strengthen the  
419 interpretation of trends on farmland. Especially the presented Low scenarios and the reduced  
420 indicator set options should be complemented by additional targeted monitoring; for instance by  
421 focusing on endangered species, or on biodiversity hotspots or sinks (Kleijn *et al.* 2011), by using

422 remote sensing information (Duro *et al.* 2007) or by integrating them with existing monitoring  
423 schemes. Still, the focus of the proposed monitoring scheme, namely detecting the impact of  
424 changes in management (resulting from policy measures) on farmland biodiversity should be  
425 considered. For instance, the proposed monitoring design can be combined with bird data, but the  
426 high mobility of birds and their dependence on landscape patterns instead of individual farms,  
427 restrict the potential of data integration.

428 The three invertebrate groups included in the proposed full indicator set (earthworms, spiders, bees)  
429 are related to major ecosystem services (decomposition, pest control, pollination) which are  
430 particularly relevant in an agricultural context. The reduced indicator set obviously lacks this  
431 information. It is nonetheless a commonly used combination of indicators (i.e. habitat and plant  
432 data) as proxies in biodiversity monitoring (the UK Countryside Survey  
433 (<http://www.countrysidesurvey.org.uk>), the Swedish NILS [Ståhl *et al.* 2011]). The reduced indicator  
434 set still comprises farm management information, which allows analysis of causal relationships  
435 between changes in species richness and agricultural practices. Although methods for cross  
436 monitoring scheme assessments are not yet well developed (Henry *et al.* 2008), already the reduced  
437 indicator set including environmental and management information, plant and habitat data could  
438 provide a central backbone for data integration of existing monitoring schemes and could be linked  
439 to alternative fauna indicators.

440

#### 441 *Recommendations for future monitoring*

442 Monitoring is not only needed to determine progress towards an objective, but can also render  
443 investments more effective, like in the case of controlling invasive species (Bogich, Liebhold & Shea  
444 2008), the protection of nature areas (Balmford & Gaston 1999) or in avoiding costly (irreversible)  
445 losses (Armsworth *et al.* 2012). The presented farmland biodiversity monitoring scheme provides a  
446 starting point for further refinement and planning purposes at European, national or regional scale.  
447 The full indicator set originated from an extensive stakeholder consultation process followed by an  
448 information redundancy analysis. Therefore, decisions to include fewer indicators or lower sampling  
449 densities should be done only after extensive additional analysis.

450 There is potential to use the proposed sampling design to integrate data from different monitoring  
451 schemes, as well as that the outputs of the monitoring are likely to inform multiple policy objectives  
452 rather than just the CAP. Regardless of the potential, the implementation of the proposed  
453 monitoring scheme seems already economically feasible and sharing of its costs across policy  
454 instruments politically attractive, especially for a land use sector that is supposed to provide  
455 important ecosystem services for the future.

456 Adaptation of monitoring schemes over time is common practice (see for instance LUCAS [EUROSTAT  
457 2009] or the NILS [Ståhl *et al.* 2011]) to improve data collection efficiency and to ensure the  
458 relevance of data collected with regards to new changes in policies, agricultural management or new  
459 biodiversity trends, e.g. the recently identified bee mortality. Whereas such adaptations potentially  
460 cause problems in terms of interoperability of data over years, it is unlikely that everything can be  
461 foreseen in detail in advance and proposed monitoring schemes should have a certain degree of  
462 flexibility (Lindenmayer & Likens 2009). The monitoring scheme proposed in this paper can be  
463 adapted by changing methods, adding or removing indicators, adding or removing regions or  
464 countries and by adjusting the number of farms to be sampled.

465

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479

### 480 **Supporting Information**

481 Additional supporting information may be found in the online version of this article.

482 Appendix S1. Method description, errors and uncertainties

483 Table S1.1. Summary of the sampling effort over the BioBio case studies.

484 Table S1.2. Overview of required farm sample size estimates per case study.

485 Fig. S1.1. Overview of the input data and assessments performed in this study.

486 Fig. S1.2. Overview of the different steps in the collection of biodiversity data.

487 Fig. S1.3. Accumulation curves for plant, earth worm, spider and bee species richness in the 12 case  
488 studies.

489 Appendix S2. Cost estimations for monitoring

490 Table S2.1. Adaptation of costs from the monitoring pilot phase.

491 Table S2.2. The costs for biodiversity monitoring of a standardized farm (in Euro).

492 Fig. S2.1. Estimated cost allocation for five budget components.

493 Appendix S3. Spatial distribution of farms and regions delineation within Europe

494 Table S3.1. Number of farms per farm type per European region.

495

496 **Data Accessibility:** The species richness data used in this study are available from the Dryad Digital  
497 Repository: <http://dx.doi.org/10.5061/dryad.kc688> . The used cost data can be found in Appendix S2  
498 and in Targetti et al. 2014.

499

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647 **Tables**648 **Table 1.** Required sample size (number of farms to be sampled) per case study per species indicator to identify a 10% change in species richness in five years

Case study region			Estimated number of farms to be sampled within the case study region and of the indicated farm type to allow for the detection of a 10% change in species richness in five years (confidence interval 95% included in brackets).			
No	Country	Farm type	Plants	Earthworms	Spiders	Bees
1	Austria	Field crops and horticulture (n=16)	52 (36 -68)	87 (48 – 126)	105 (77 – 133)	427 (274 – 580)
2	Bulgaria	Specialist grazing livestock (n=16)	46 (35 – 57)	142 (61 – 223)	65 (38 – 92)	148 (95 – 201)
3	France	Field crops and horticulture (n=16)	37 (27 -47)	22 (12 – 32)	22 (13 – 32)	137 (101 – 173)
4	Germany	Mixed crops and livestock (n=16)	27 (18 – 36)	24 (10 – 38)	42 (26 – 58)	465 (239 – 691)
5	Hungary	Specialist grazing livestock (n=18)	37 (27 – 47)	356 (250- -462)	239 175 – 303)	247 (115- -379)
6	Italy	Permanent crops (n=18)	25 (16- -34)	22 (101 – 341)1	144 (76 – 212)	167 (105 – 229)
7	The Netherlands	Field crops and horticulture (n=14)	29 (19 – 39)	110 (39 – 181)	197 (132 – 262)	164 (31 – 297)
8	Norway	Specialist grazing livestock (n=12)	20 (14 –b26)	38 516 – 60)	42 (25 – 59)	50 (22 – 78)
9	Spain	Specialist grazing livestock (n=10)	19 (13 – 25)	123 (35 – 211))	47 (27 – 67)	77 (30 – 124)
10	Spain	Permanent crops (n=20)	140 (113 – 167)	226 (148 – 304)	172 (133 – 211)	279 (164 – 394)
11	Switzerland	Specialist grazing livestock (n=19)	50 (39 – 61)	27 (12 – 42)	97 (67 – 127)	129 (82 – 176)
12	Wales	Specialist grazing livestock (n=20)	22 (16 – 28)	22 (11 – 33)	39 (28 – 50)	59 (22 – 96)

649 **Table 2:** Required farm sample percentage for each of the four farm types for the full and the  
650 reduced indicator sets and for the High (H), Average (A) and Low (L) scenarios

	Full indicator set			Full indicator set excl. Bees			Reduced indicator set		
	H	A	L	H	A	L	H	A	L
Field crops and horticulture (n=3) [%]	5.12	1.96	0.59	3.45	0.87	0.16	0.62	0.32	0.16
Grazing livestock (n=3) [%]	10.77	2.72	0.87	10.77	2.72	0.57	1.12	0.42	0.23
Mixed (n=1) [%]	4.91	4.91	4.91	0.44	0.44	0.44	0.28	0.28	0.28
Permanent crops (n=2) [%]	1.70	0.75	0.52	1.38	0.75	0.52	0.85	0.28	0.06

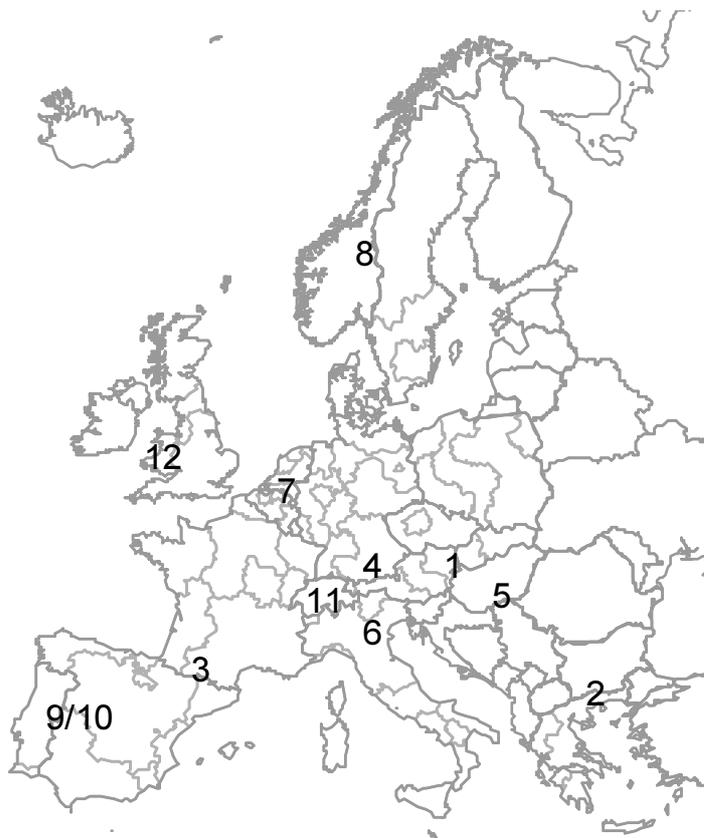
651 **Table 3:** Monetary and relative cost estimates for the nine sampling scenarios, in relation to the total  
652 CAP budget (2014–2020; 408.3 billion Euro) or to the part allocated to environmental and  
653 biodiversity targets, the “green” CAP budget (122.5 billion Euro). Numbers in grey present budget  
654 shares below 0.5%, the lowest allocation found in literature (EC 2004)

Reference budget	Scenarios options	High farm sample size option	Average farm sample size option	Low farm sample size option
Annual cost estimations for the 5 years rolling survey	Full indicator set	Mio € 433	Mio € 179	Mio € 103
	Full set excl. Bees	Mio € 307	Mio € 85	Mio € 24
	Reduced indicator set	Mio € 28	Mio € 13	Mio € 7
Percentage of the total annual CAP budget	Full indicator set	0.74%	0.31%	0.18%
	Full set excl. Bees	0.53%	0.15%	0.04%
	Reduced indicator set	0.05%	0.02%	0.01%
Percentage of the annual CAP budget allocated to green targets	Full indicator set	2.48%	1.02%	0.59%
	Full set excl. Bees	1.75%	0.15%	0.14%
	Reduced indicator set	0.16%	0.08%	0.04%

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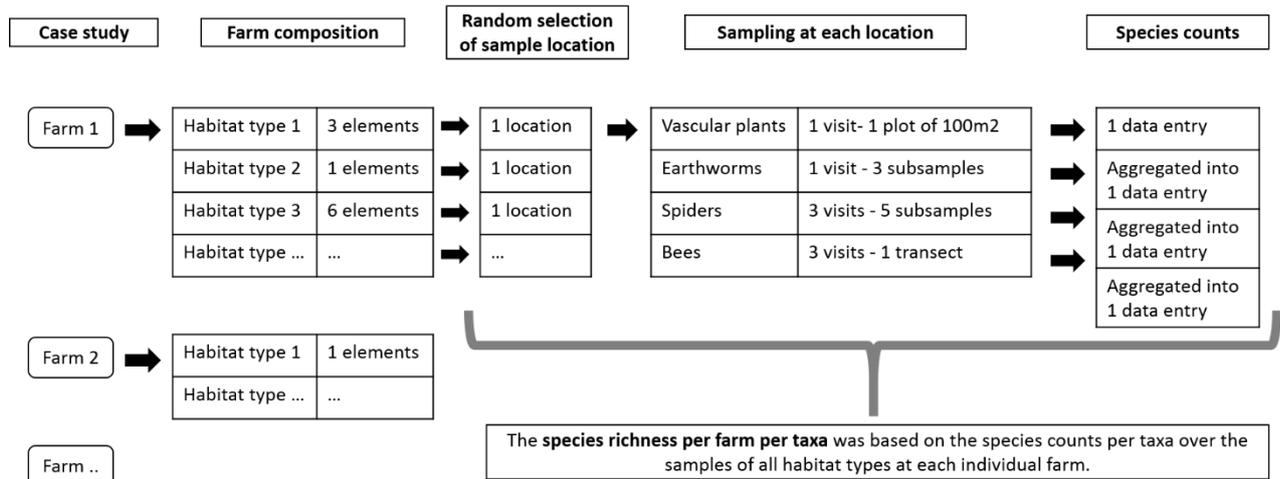
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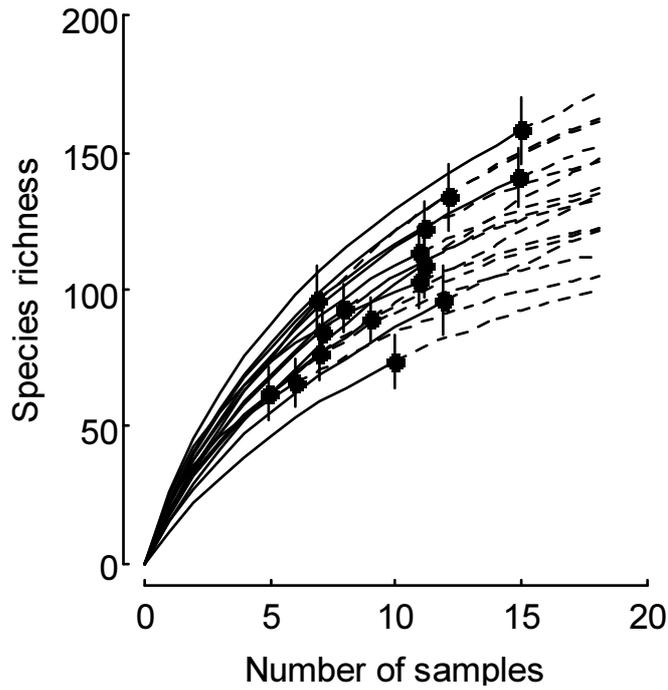
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660 *Figure 1: Overview of the case study regions and the zones that served to develop the spatial*  
661 *sampling design. Numbers of case studies correspond to those in Table 1.*



662

663 Figure 2. Overview of the computation of the species richness per taxa per farm.



664

665 *Figure 3: Example of accumulation curves for plant species richness in 16 farms in the French*  
 666 *case study. Dots with bars are observed species richness with 95% confidence interval. Solid*  
 667 *curves are species rarefaction curves, dotted curves are extrapolation curves. As the taxa were*  
 668 *sampled using a stratified sampling approach, the number of samples (x-axis) is identical to the*  
 669 *number of habitat types found per farm.*

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671



Indicator sets Required farm sample sizes	Biodiversity Information scenarios								
	Full indicator set			Full indicator set excl. Bees			Reduced indicator set		
	H	A	L	H	A	L	H	A	L
<b>Indicators</b>	→			→			→		
Farm management	5.12	1.96	0.59	3.45	0.87	0.16	0.62	0.32	0.16
Habitats	5.12	1.96	0.59	3.45	0.87	0.16	0.62	0.32	0.16
Plants	5.12	1.96	0.59	3.45	0.87	0.16	0.62	0.32	0.16
Earthworms	5.12	1.96	0.59	3.45	0.87	0.16			
Spiders	5.12	1.96	0.59	3.45	0.87	0.16			
Bees	5.12	1.96	0.59						

Reduction of information

Reduction of robustness

672

673 Figure 4: Indicators included per scenario as well as estimates of the farm sample sizes for the Field  
 674 crops and horticulture farm type (% of the total number of farms of that farm type per region). The  
 675 information output is reduced between the indicator sets from left to right and the robustness of the  
 676 data output decreases from high (H) over average (A) to low (L).

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