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Use of extensive habitat inventories in biodiversity studies

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14 **Abstract**

15 Large monitoring programs exist in many countries and are necessary to assess
16 present and past biodiversity status and to evaluate the consequences of habitat
17 degradation or destruction. Using such an extensive data set of the floristic richness in
18 the Paris Ile-de-France region (France), we compared different sampling efforts and
19 protocols in different habitat units to highlight the best methods for assessing the actual
20 plant biodiversity.

21 Our results indicate that existing data can be used for a general understanding of
22 site differences, but analysts should be aware of the limitations of the data due to non-
23 random selection of sites, inconsistent observer knowledge, and inconsistent sampling
24 period. The average species diversity recorded in a specific habitat does not necessarily
25 reflect its actual diversity, unless the monitoring effort was very strong.

26 Overall, increasing the sampling effort in a given region allows improvement of
27 the (i) number of habitats visited, (ii) the total sampled area for a given habitat type, (iii)
28 the number of seasons investigated. Our results indicate that the sampling effort should
29 be planned with respect to these functional, spatial and temporal heterogeneities, and to
30 the question examined. While the effort should be applied to as many habitats as
31 possible for the purpose of capturing a large proportion of regional diversity, or
32 comparing different regions, inventories should be conducted in different seasons for
33 the purpose of comparing species richness in different habitats.

34

35

36

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37 **Keywords:** data quality; floristic diversity; monitoring; sampling effort; species

38 richness

39

40

41 Introduction

42 It is now widely recognized that the current extinction rates of plant and animal
43 species are between a hundred and a thousand times higher than the background rates
44 throughout life's history on Earth (May 2002). However, documenting species
45 extinction only, i.e. the most obvious manifestation of biodiversity loss, is not sufficient
46 to develop effective conservation policies, partly because extinction rates carry no
47 information regarding changes in community composition, which may have dramatic
48 consequences for ecosystem stability (Worm et al. 2003). There is an urgent need to
49 quantify the spatiotemporal changes in biodiversity by considering community
50 composition and trends in species abundances (Convention on Biological Diversity in
51 Rio, 1992). Such information is necessary to identify the mechanisms (e.g.
52 environmental variables, human-induced disturbances, etc.) controlling the variation in
53 species richness through space and time, as well as to identify sites of conservation
54 concern and appropriate policies to improve the current biodiversity.

55 Ideally, this quantification would require large scale, long-term surveys based on
56 standardized methodologies to allow comparisons in space and time. Such protocols
57 already exist in a limited number of cases or are just starting to be implemented. The
58 British Countryside Survey (CS) (Firbank et al., 2003; Haines-Young et al., 2003), for
59 example, was established in 1978 in the United Kingdom and focuses on several
60 taxonomic groups, including plants. The Biodiversity Monitoring Program (BDM) in
61 Switzerland (Weber et al., 2004; Plattner et al., 2004) was launched in 1995 and focuses
62 on local plant diversity. Other protocols have been implemented to survey the diversity
63 of particular taxonomic groups, as exemplified by breeding bird surveys in different
64 countries (since 1966 in North America, Sauer et al. 1997; since 1994 in UK, Newson et

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65 al. 2005; since 1989 in France, Julliard et al. 2003). Such surveys are based on
66 formatted sampling protocols generally occurring twice a year within different discrete
67 classes of habitat at the national scale. In these examples, the inventory protocol is
68 generally standard and well defined, which allows the sampling effort to be
69 homogeneous among observers, constant in time, or clearly quantified, so that any
70 statistical inference can be made independently of the monitoring effort. Moreover,
71 inventory protocols are designed to ensure that sampling is proportional to the area
72 occupied by each habitat / settlement type in the region of interest.

73

74 Although such large scale monitoring schemes are crucial to document future
75 changes in biodiversity, they will unfortunately not suffice to quantify the present
76 changes in biodiversity, and specifically to evaluate the 2010 biodiversity target. A
77 complementary approach to quantify changes in biodiversity could be to use the large
78 amounts of existing inventory data collected by various biodiversity stakeholders (some
79 of which are compiled in the Global Biodiversity Information Facility, GBIF 2008).
80 However, because such data come from a very large number of observers and
81 geographic locations, they were generally collected using very different methodologies
82 and are highly heterogeneous in nature. The question that immediately arises is whether
83 such heterogeneous data can be exploited to document reliably the trends in
84 biodiversity.

85 Here we address this issue using plant inventory data from Paris Basin (France).
86 We analyzed data from thousands of inventories carried out between 2001 and 2005 by
87 botanists who were involve in the same Botanical Conservatory but who were not
88 instructed to follow a given standardized protocol. Focusing on the proportion of total

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89 vascular plant species detected as a function of (1) annual number of visits per habitat
90 type and (2) season of data collection, we investigated different options for data analysis
91 and survey protocol, to optimize the use of existing data and improve future monitoring.
92 We specifically addressed the following questions: 1) Are one time surveys of floristic
93 diversity indicative of the total diversity of a region, and do species richness estimated
94 from one time surveys vary across habitats, seasons and years? 2) What is the benefit of
95 increasing survey effort, by increasing either the number of survey habitats or the time
96 span of surveys?

97

98 **Material and methods**

99 **Study area**

100 The Ile-de-France region, including the city of Paris (48°68' N; 0°17' E) and the
101 surrounding area, covers 12,072 km² (Fig. 1). The climate is oceanic with continental
102 trends (mean annual temperature 12 °C, with a minimum in January and a maximum in
103 July; average monthly rainfall 57 mm) and the relief is relatively flat (elevation between
104 11 and 217 m a.s.l.). The population density is 952 inhabitants/km² (INSEE 2006),
105 which makes Ile-de-France the most densely populated administrative region of France.

106 A total of 1225 plant species were encountered in the study area between 2001
107 and 2005, as calculated from records of the FLORA database (National Botanical
108 Conservatory of the Paris Basin, CBNBP 2008 and see below for a description of the
109 database). Of these species, 11% were naturalized species, i.e. non-indigenous species
110 that reproduce and sustain populations without direct intervention by humans
111 (Richardson et al. 2000).

112

113 **Inventory protocol**

114 The data used in this study were collected between 2001 and 2005 by botanists
115 from the National Botanical Conservatory of the Paris Basin (hereafter CBNBP), a
116 French public organization aiming to study and protect the flora of the Paris basin. One
117 central objective of CBNBP is to describe the geographical distribution of all species
118 growing in the area, which dictates the methodology used to collect data. Every year, a
119 total of 149 botanists (both professionals and competent amateurs) visited the
120 'communes' (French administrative municipalities) of the region between March and
121 October and recorded as many plant species as they could observe within a

122 municipality, as well as the spatial locations of each species. There was no standardized
123 protocol: the duration of data collection, sampling locations and total area sampled were
124 left to the appreciation of the observers and varied greatly among individuals. For
125 example, sampling locations within a municipality were not randomly distributed, but
126 were instead usually chosen to maximize the total number of species observed.

127

128 **Database contents and study data**

129 Inventory data were pooled in FLORA, a database built by CBNBP. The
130 database includes information on species (scientific and common names), observer, date
131 of observation, location (municipality) and habitat type according to CORINE land
132 cover nomenclature (Bissardon et al. 1997), and contains more than one million
133 observations (i.e. one species recorded at a given time and in a given site) for the Ile-de-
134 France region (CBNBP 2008).

135 We chose to work with data collected between 2001 and 2005, because the
136 quality and quantity of data are much lower before this period. For statistical reasons,
137 we also discarded all observations from rarely sampled habitats, i.e. habitats that were
138 visited less than once a month between 2001 and 2005, so that data from eight habitat
139 types only were retained (see Table 1). For this study, this yielded a total of 237,884
140 observations corresponding to 7,358 different sites (i.e. the total area covered by a given
141 habitat type in a given place) within the Ile-de-France region.

142

143 **Data analysis**

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144 Because the database contains very little information on species abundance or
145 frequency, and does not allow estimating species detection probabilities, plant
146 communities were characterized by the observed species richness only.

147

148 *Species richness at the site level*

149 We first analyzed the variation in species richness at the site level by fitting an
150 analysis of variance model using the R software (Core Team 2007), where site richness
151 was a function of (1) habitat type (2) inventory month, (3) inventory year, and (4) all
152 pairwise interactions.

153 As this analysis showed statistical differences among years on the richness
154 recorded, all years were considered separately in subsequent analysis.

155

156 *Assessment of optimal monitoring effort*

157 To optimize monitoring programs, monitoring effort should be minimum, but
158 large enough to provide accurate estimates of species richness (and, ideally, other
159 parameters of community composition). To evaluate this, we performed random
160 resampling in the database to simulate various monitoring efforts, by varying the
161 number of sites, habitats, or months sampled.

162 *a) Increasing effort within a given habitat*

163 To estimate the species accumulation curve within each habitat type, we
164 plotted the ratio of observed vs. total species richness as a function of the number of
165 inventories, x , as follows. Within a given year, x inventories (= x sites) were sampled at
166 random, each in a different month, and the overall species richness (excluding
167 redundancies) of this sample was computed. This species richness was then divided by
168 the total number of species observed in this habitat type. For each x and each habitat

169 type, the procedure was repeated 50,000 times and the average ratio of observed vs.
170 total species richness was plotted.

171

172 *b) Correlation between sampled and total species richness*

173 To test whether the number of species recorded in x inventories was
174 representative of the “true” floristic richness of the different habitats, we compared the
175 number of species recorded in x inventories within a year in each habitat to the overall
176 number of species in each habitat, using a Spearman rank correlation across habitats.
177 This procedure was performed 50,000 times for each habitat, and the average
178 correlation coefficient, r_s , as well as the proportion of significant correlations at the 5%
179 level were plotted as a function of the number of inventories per habitat, x .

180 *c) Optimization of the number of habitats or months sampled*

181 We compared the benefit of increasing the number of months or the number of
182 habitats sample, given a constant effort. To this end, we plotted the observed species
183 richness as a function of number of habitats (respectively months) visited, with a
184 constant number of inventories. Keeping the number of inventories (8) constant allowed
185 us to test for a habitat or month effect without confounding area effects. Within a given
186 year, eight sites were chosen at random among x habitat types (respectively months) and
187 the overall species richness in these eight inventories (i.e., excluding redundancies) was
188 computed. The procedure was repeated 50,000 times and the average species richness in
189 x habitats (respectively months) was plotted against the number of habitats (months).

190

191 Results

192 **Variation in average observed species diversity**

193 Site species richness varied significantly across years, months (maximum
194 species richness in June (36.5), minimum in August (28)), and habitat types (maximum
195 number of species in cities and industrial sites (41), minimum in stagnant freshwater
196 (18), Table 2). In addition, all interactions were also significant, so that the difference in
197 species richness among habitats were highly variable within and across years (Table 2).

198

199 **Species accumulation curves within habitats**

200 The shape of the species accumulation curves varied greatly across habitats (Fig.
201 2). The proportion of total species recorded appeared to reach a plateau at five
202 inventories per habitat in mesophile meadows, cultures, cities and industrial sites or
203 wastelands. Note however that the fraction of total species observed remained low
204 (between 15 and 25%). In contrast, the species accumulation curves did not appear to
205 saturate in stagnant fresh water, circle of water edges, deciduous forest or urban parks
206 and gardens.

207

208 **Correlation between observed and total species richness across habitats**

209 As expected, the correlation between observed and total species richness across
210 habitats was close to zero and non-significant when the number of inventories per
211 habitat was small ($x < 6$, Fig 3). However, seven or eight inventories per habitat
212 provided a better picture of the total species richness (Spearman correlation coefficient
213 significantly different from 0, Fig. 3a). Note however that mean correlation coefficients
214 remained relatively low (fig 3a), suggesting that yearly monitoring protocols with few

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215 inventories in each habitat do not allow to compare species richness in the different
216 habitats.

217

218 **Optimization of monitoring effort by increasing the number of habitats or months**

219 As expected, observed species richness increased (+ 12%) when the number of
220 habitats increased for a constant monitoring effort. Similarly, there was a lower but non
221 negligible benefit (+7%) of increasing the number of inventory months.

222

223

224 Discussion

225 Biodiversity inventories are costly in time and money, and maximizing the
226 number of species observed during a given monitoring effort is therefore an important
227 task. Our study focuses on the use of existing, non standardized inventory data to
228 address the optimization of monitoring effort.

229

230 **Non-standardized data and minimal monitoring effort**

231 Our results reflect the well-known heterogeneity of plant communities in time
232 (year) and among habitat types: the observed species richness depends on the habitat,
233 season, year and their interactions. When dealing with non-standardized data, this raises
234 the issue of how to disentangle actual ecological sources of heterogeneity (e.g. true
235 differences among habitat, seasons, years...) from sampling or methodological sources
236 of variation. In particular, owing to the lack of randomization and to observer
237 variability, among-inventory differences in species richness were not only due to
238 differences in the period of sampling (month and year), but also to differences in sites
239 themselves (inventories performed in different months were not necessarily conducted
240 on the same sites). This for example implies that classical methods to estimate species
241 richness (e.g. those derived from the CAPTURE program, Rexstad and Burnham 1991)
242 cannot be used with such non-standardized inventory data. Hence, total species richness
243 in a given habitat was estimated as the total number of species observed over a large
244 number of inventories. Although this probably results in an underestimation of species
245 richness, we nonetheless believe that it provided a reasonably good picture of
246 community composition.

247 General guidelines about minimal monitoring efforts can be inferred from the results
248 above. We showed that one to five yearly inventories per habitat do not provide an
249 accurate picture of habitat richness (Fig. 4), at least in the semi-natural habitats
250 commonly encountered in Île-de-France. Sampling effort is clearly an important issue
251 regardless of the survey method used (Metcalf-Smith et al. 2000; Walther & Martin
252 2001), and other studies have reached similar conclusions regarding minimal sampling
253 efforts. For example, De Solla et al. (2005) showed that, in anuran monitoring
254 programs, the average observed species richness was only 25.1% of the total richness
255 with a single sampling night, but reached an average of 80% of the total species
256 richness with 12 sampling nights. Archaux et al. (2006) showed that on 400 m² forest
257 quadrats, the level of exhaustiveness of plant censuses increased in a semi-logarithmic
258 way with sampling time. The study of Estevez & Christman (2006) on the movement of
259 animals in confinement clearly indicated that sampling effort had a tremendous impact
260 on the study outcome. Nonetheless, several European countries have started to
261 implement floristic monitoring programs, generally based on one or two inventories per
262 year. For instance, in the United Kingdom, the British Countryside survey (Haines-
263 Young et al. 2000) is based on annual inventories of several hundred of randomly
264 sampled fix plots classified into 32 land use classes. In Switzerland, The Biodiversity
265 Monitoring Program (Hintermann et al. 2002) consists in a grid-sampling program
266 based on five settlement types within which plots are randomly drawn. The local plant
267 diversity is inventoried in these plots every five years.

268 Although the information collected in the aforementioned monitoring programs is
269 useful to document long-term trends, or to compare trends among habitat types
270 (especially for the most frequent species, and when directional variations in species

271 abundances are high), our results suggest that it will not be sufficient to compare the
272 absolute species numbers present in the different habitat types. In the present data set,
273 the variability across observers and sites tended to overwhelm the differences among
274 habitat types when there were fewer than six inventories per year (Fig. 4), which
275 represents a large monitoring effort in comparison with most survey programs.

276

277 **Optimization of sampling effort**

278 The outcome of a given protocol depends, among others, on the area sampled as
279 well as on seasonal and habitat effects, so that the sampling effort should be judiciously
280 planned and implemented to optimize the number of species recorded. In general, the
281 financial and time costs of a field inventory do not vary across seasons or habitat types
282 and protocols can be optimized via a selection of seasons and habitats visited. For
283 example, with a constant effort, the observed species richness was increased by 6.5% if
284 inventories were conducted in two different seasons vs. a single season, and by 11 % if
285 they were conducted in two vs. one habitats. This is consistent with the generally
286 accepted idea that plant functional beta diversity is larger than seasonal beta diversity.
287 However, the choice of maximizing either the number of seasons or habitats sampled
288 should depend on the question investigated.

289 If a monitoring program aims to maximize recorded species richness in the study
290 region (e.g. for the purpose of comparing biodiversity across regions or examining
291 annual trends), maximizing habitat types would be the most efficient strategy. In fact,
292 our results indicate that (i) increasing the number of habitats is always more efficient
293 than increasing the number of months; (ii) beyond three months, any further increase in
294 the number of months sampled has no notable effect on the observed species richness

295 for a constant number of sites visited (Fig.4). In contrast, to compare species richness
296 across habitats, inventories should be conducted throughout as many sites as possible to
297 ensure that actual differences among habitats can be detected. Assuming that the total
298 species richness was a proxy for true total species richness, we showed that the average
299 species richness observed during a single inventory per habitat was not representative of
300 total richness. First, the average species richness observed in a single inventory was
301 only 4.24 ± 2.84 % of total richness on average. Second, (b) observed richness is not
302 representative of the total richness of the habitat unless the sampling effort is extremely
303 strong (> 5 inventories a year, figure 3). It follows that for a constant sampling effort,
304 among habitat comparisons require to use few habitats with many inventories per
305 habitat.

306

307

308 Conclusion

309 There is general agreement that biodiversity conservation should be guided by
310 biodiversity assessment. As an important part of this assessment, inventory protocols
311 should be designed with care, to identify the specific conservation target that a project
312 ultimately would like to influence (Salafsky et al. 2002). Ideally inventories should
313 include (1) sites randomly sampled according to a standard protocol (for example, using
314 a sampling effort stratified by habitat types), (2) observers with a knowledge level as
315 uniform as possible (3) identical observation periods. As we promote these goals we
316 will promote high quality data for monitoring and other purposes. Existing large data
317 sets collected by various biodiversity stakeholders do not generally meet these criteria,
318 and they should be used with caution to infer biodiversity trends, e.g. in combination

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319 with resampling methods to correct for their heterogeneity. The large number of
320 existing inventory data can however be exploited to address other conservation issues,
321 e.g. to quantify floristic index over a homogeneous region (Muratet et al. 2008).

322

323

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328

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- 392
- 393

394 **Tables**

395

396 Table 1 Description of habitats types. The distribution of the number of inventories
 397 across habitat types between 2001 and 2005 and the spatial distribution of habitats
 398 are given.

399

| HABITAT type | Number of visits by surveyors | Proportion of the total study area (%) (IAURIF 2003) |
|-----------------------------------|----------------------------------|---|
| Stagnant fresh water | 412 | 1.2% |
| Circle of water edges | 437 | |
| Mesophile meadows | 259 | not available |
| Deciduous forests | 2072 | 20.5% |
| Cultures (essentially cereals) | 257 | 51.2% |
| Urban parks and gardens | 1012 | 4% |
| Cities and industrial sites | 1596 | 15.6% |
| Wastelands | 1313 | 0.36% |

400

401

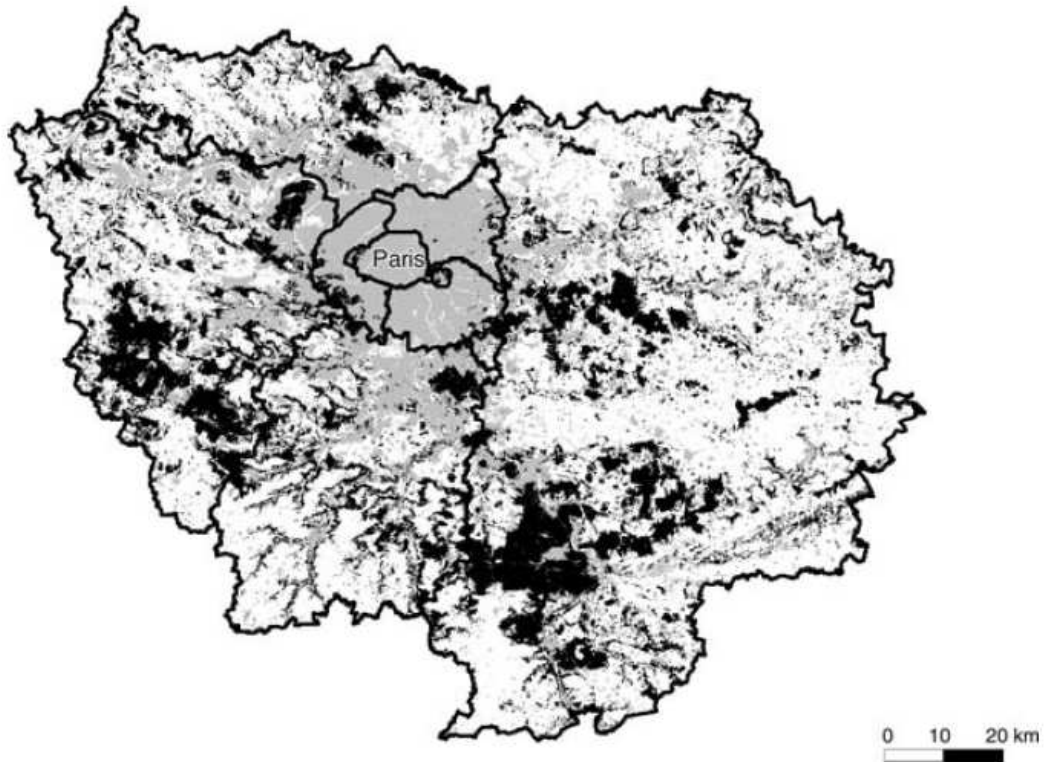
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402 Table 2 Result of the analysis of variance, where site richness was a function of (1)
 403 habitat type (2) inventory month, (3) inventory year, and (4) all pairwise interactions.
 404

| Parameters | Degree of | | Pr(>F) |
|--------------------|-----------|---------|-------------------|
| | freedom | F value | |
| Habitat | 7 | 135.82 | <10 ⁻⁴ |
| Month | 7 | 22.94 | <10 ⁻⁴ |
| Year | 4 | 31.20 | <10 ⁻⁴ |
| Habitat*month | 49 | 4.20 | <10 ⁻⁴ |
| Habitat*year | 27 | 6.14 | <10 ⁻⁴ |
| Month*year | 27 | 5.26 | <10 ⁻⁴ |
| Habitat*month*year | 165 | 1.78 | <10 ⁻⁴ |

406
 407

408 **Figures**

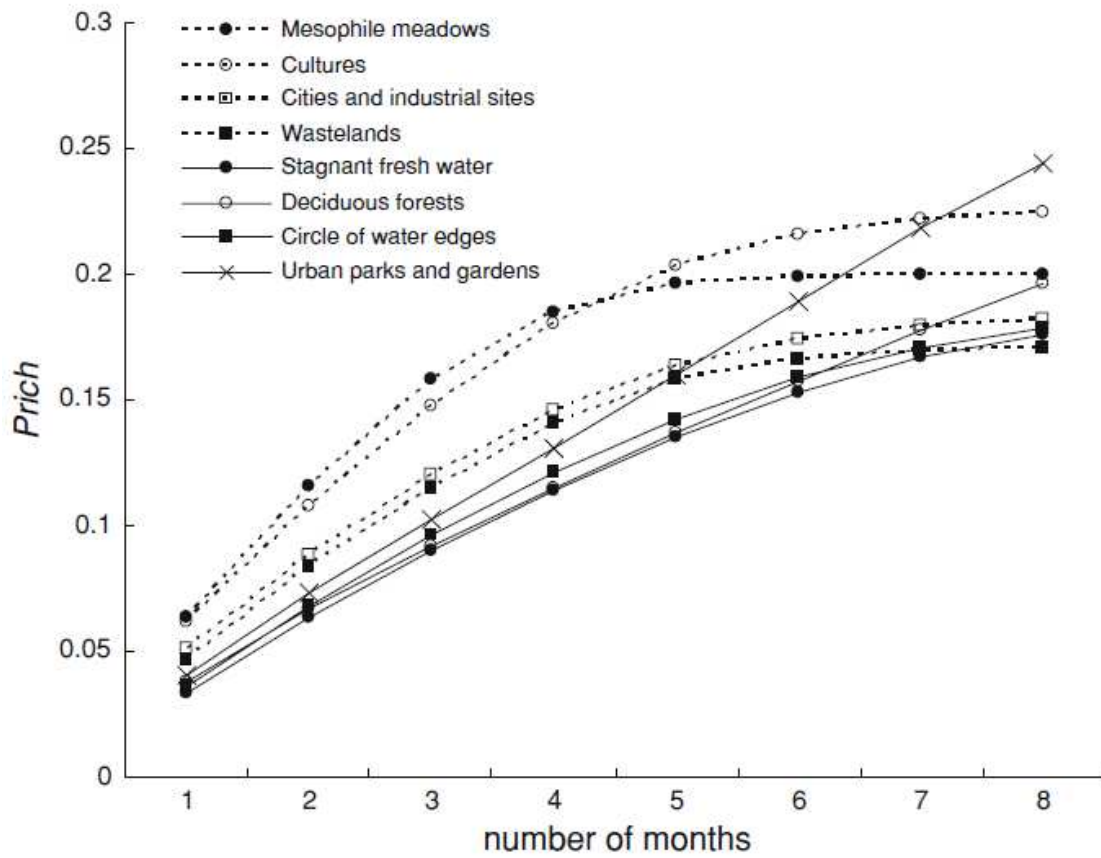


409

410 Fig. 1 Map of the study area, the Paris Ile-de-France region. Forests appear in black,
411 cultures and other rural habitats in white and open and built urban area in grey
412 (IAURIF 2003). Dark lines correspond to the district boundaries

413

414

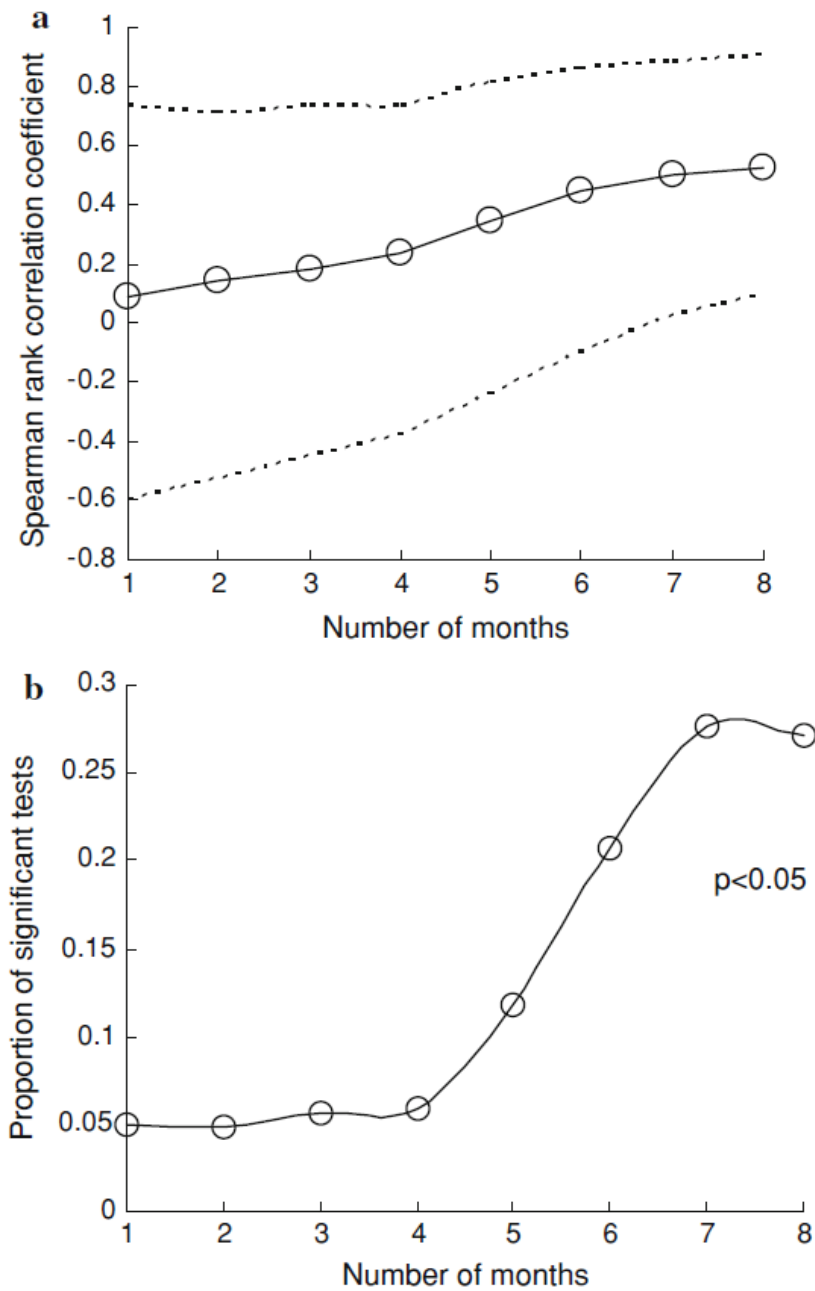


415

416 Fig. 2 Proportion of total species richness (Prich) as a function of the number of

417 seasons sampled (number of months)

418



419

420 Fig. 3 Correlation between overall and recorded species richness in the different
 421 habitats, as a function of the monitoring effort (increase of the number of inventory
 422 months x). Protocol presented in method section. a Average (open circles) and 95%
 423 confidence intervals (dashed lines) Spearman coefficients of rank correlation r_s . b
 424 Proportion of significant one-tailed correlations between overall and recorded species
 425 richness among 50,000 independent computations of recorded species richness.

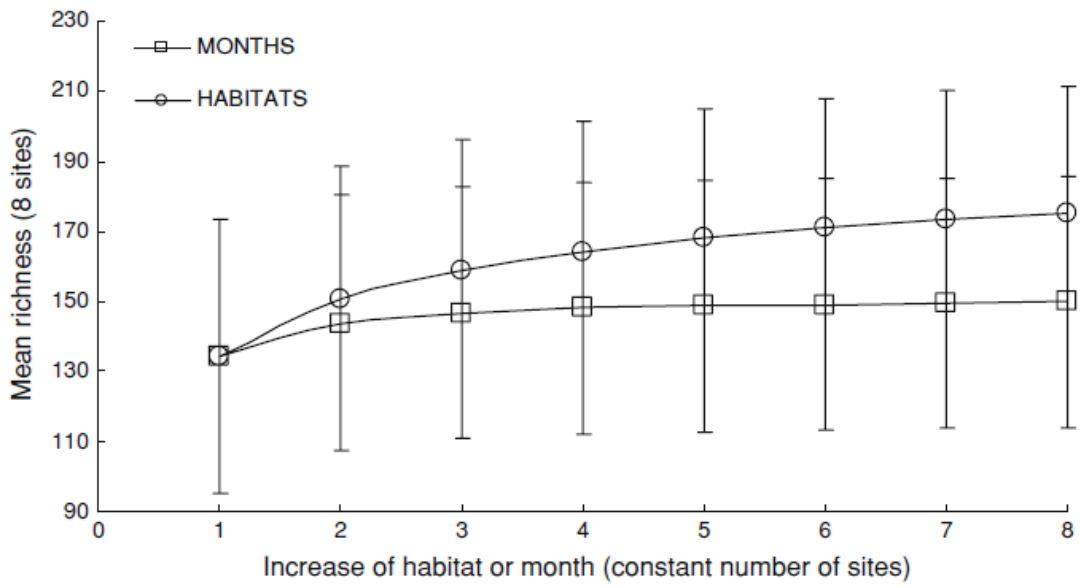
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431

432 Fig. 4 Observed species richness as a function of the number of months or habitats

433 visited for a constant effort (eight sites sampled). Error bars represent standard errors.