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Assessing the emergence of pro-biodiversity practices in citizen scientists of a backyard butterfly survey

Nicolas Deguines, Karine Princé, Anne-Caroline Prévot, Benoît Fontaine

► **To cite this version:**

Nicolas Deguines, Karine Princé, Anne-Caroline Prévot, Benoît Fontaine. Assessing the emergence of pro-biodiversity practices in citizen scientists of a backyard butterfly survey. *Science of the Total Environment*, 2020, 716, pp.136842. <10.1016/j.scitotenv.2020.136842>. <hal-02553145>

HAL Id: hal-02553145

<https://hal.science/hal-02553145v1>

Submitted on 10 Jul 2020

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HAL Authorization

Manuscript Number: STOTEN-D-19-15895R1

Title: Assessing the emergence of pro-biodiversity practices in citizen scientists of a backyard butterfly survey

Article Type: Research Paper

Keywords: Citizen scientists, Lepidoptera, Pro-environmental behaviors, Nature-based monitoring program, Urban green spaces.

Corresponding Author: Dr. Nicolas Deguines, Ph.D.

Corresponding Author's Institution: Université Paris-Sud

First Author: Nicolas Deguines, Ph.D.

Order of Authors: Nicolas Deguines, Ph.D.; Karine Princé; Anne-Caroline Prévot; Benoît Fontaine

Abstract: By monitoring biodiversity through citizen science programs, volunteers help scientists gather data at unprecedented temporal and geographical scales, and increase their knowledge and awareness of the surrounding biodiversity. While scientific outcomes of such programs may in the long run improve the state of biodiversity by informing environmental policies, direct benefits to biodiversity could arise locally if such experience of nature lead to biodiversity-friendly behaviors in volunteers. However, whether engagement into nature-based CS programs promotes individual behavioral changes remains poorly known. Here, we explored whether sustained participation in a nature-based citizen science program, called the French Butterfly citizen science project, is associated with changes in individual gardening practices. Specifically, using information provided by volunteers (n = 2362, from 2006 to 2013), we quantified gardening practices that directly affect butterflies, through two different indices: provision of nectar resources, and pesticide use.

We found quantitative evidence that individual gardening practices shifted with multi-year participation, towards increased provision of nectar resources and decreased use of pesticides. However, the reduction in pesticide use was weakened if the backyard was used to grow fruits or vegetables. Other variables such as the size of the backyard affected gardening practices.

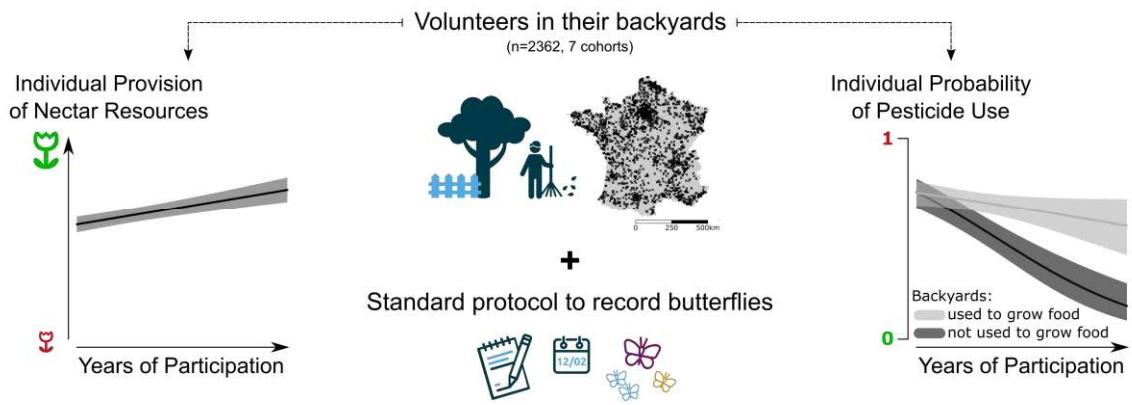
This study reveals that participation in a nature-based citizen science program can prompt biodiversity-friendly behaviors, and highlights citizen science not only as a way to collect ecologically sound data but also as a direct conservation tool. Yet, future interdisciplinary research remains critical to overcome factors limiting firm adoption of pro-biodiversity behaviors.

Response to Reviewers: Ms. Ref. No.: STOTEN-D-19-15895

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Journal: Science of the Total Environment

Garden Butterfly Observatory



1

1 **HIGHLIGHTS**

- 2 - Annual information on gardening practices (2006-2013, 2362 volunteers) are analyzed
- 3 - Gardening practices that benefit butterflies increase with sustained participation
- 4 - Reduction in pesticide use was greatest in backyards not used to grow food
- 5 - Changing participant behaviors, citizen science can have direct conservation benefits

1 **ABSTRACT**

2 By monitoring biodiversity through citizen science programs, volunteers help
3 scientists gather data at unprecedented temporal and geographical scales, and increase their
4 knowledge and awareness of the surrounding biodiversity. While scientific outcomes of such
5 programs may in the long run improve the state of biodiversity by informing environmental
6 policies, direct benefits to biodiversity could arise locally if such experience of nature lead to
7 biodiversity-friendly behaviors in volunteers. However, whether engagement into nature-
8 based CS programs promotes individual behavioral changes remains poorly known.

9 Here, we explored whether sustained participation in a nature-based citizen science
10 program, called the French Butterfly citizen science project, is associated with changes in
11 individual gardening practices. Specifically, using information provided by volunteers (n =
12 2362, from 2006 to 2013), we quantified gardening practices that directly affect butterflies,
13 through two different indices: provision of nectar resources, and pesticide use.

14 We found quantitative evidence that individual gardening practices shifted with multi-
15 year participation, towards increased provision of nectar resources and decreased use of
16 pesticides. However, the reduction in pesticide use was weakened if the backyard was used to
17 grow fruits or vegetables. Other variables such as the size of the backyard affected gardening
18 practices.

19 This study reveals that participation in a nature-based citizen science program can
20 prompt biodiversity-friendly behaviors, and highlights citizen science not only as a way to
21 collect ecologically sound data but also as a direct conservation tool. Yet, future
22 interdisciplinary research remains critical to overcome factors limiting firm adoption of pro-
23 biodiversity behaviors.

24

25

26 **KEYWORDS:** Citizen scientists; Lepidoptera; Pro-environmental behaviors; Nature-based
27 monitoring program; Urban green spaces.

28

29

30 **1. INTRODUCTION**

31 Thirty years after Diamond’s description of the *Evil Quartet* causing extinctions
32 (Diamond, 1989), habitat change remains among the most important threats to biodiversity
33 worldwide (Godet and Devictor, 2018; IPBES, 2019). In Europe, urbanization is the prime
34 driver of land use change (EEA, 2010). The suite of environmental degradation associated
35 with urbanization (e.g., increase in impervious surfaces, air and soil pollution) generally leads
36 to a reduction in the diversity of a wide range of taxa (Marzluff, 2001; McKinney, 2006) and
37 a biotic homogenization at large geographical scales (Deguines et al., 2016; La Sorte et al.,
38 2007; McKinney, 2006). Improving the suitability of urban environments for wild species
39 thus is a conservation issue (Hall et al., 2017).

40 Within cities, backyards may constitute 16-47% of urban green space in Europe (based
41 on estimates from the UK and France), and as much as 86% as found in León, Nicaragua
42 (Baldock et al. 2019; Goddard et al., 2010; Mimet et al., 2020). Urban backyards can act as
43 refuges for biodiversity (Goddard et al., 2010; Levé et al., 2018; Sperling and Lortie, 2010),
44 and as corridors connecting green spaces (Mimet et al., 2020; Rudd et al., 2002). Yet, to fulfil
45 this potential, there is a need to improve backyard suitability for biodiversity (Daniels and
46 Kirkpatrick, 2006; Fontaine et al., 2016; Pardee and Philpott, 2014).

47 Citizen science (CS), defined as a “method of integrating public outreach and
48 scientific data collection” (Cooper et al., 2007) through “the involvement of volunteers in
49 research” (Dickinson et al., 2010), could help change the management of these private spaces
50 for greater biodiversity benefits. The success of nature-based CS programs in advancing the

51 field of ecology is well established (McKinley et al., 2017). From a conservation perspective,
52 Couvet and colleagues (2008) highlighted the greater social legitimacy of CS biodiversity
53 indicators, generated from public-collected data, which may help bridge the gap between
54 research findings and policy implementation (Arlettaz et al., 2010; Toomey et al., 2017).
55 Participating in CS programs may also increase the biodiversity knowledge of volunteers
56 (Deguines et al., 2018; Silvertown et al., 2015), and these programs are further hoped to
57 commit volunteers into heightened pro-environmental behaviors (Chase and Levine, 2018;
58 Toomey and Domroese, 2013). To date, however, evidence on whether pro-environmental
59 behaviors are adopted by volunteers is scarce and based on qualitative information from a
60 limited number of volunteers and/or a short period of time (Cosquer et al., 2012; Crall et al.,
61 2013; Jordan et al., 2011; Lewandowski and Oberhauser, 2017; Sharma et al., 2019). A
62 temporal and quantitative assessment is lacking to assess this issue.

63 In this study, we investigated whether backyard owners joining the French Butterfly
64 citizen science project (BCSP) adopt pro-environmental behaviors in their backyards.
65 Butterflies forage on nectar from flowers and the amount of nectar resources is a strong driver
66 of butterfly abundance and richness in anthropogenic landscapes (Luppi et al., 2018).
67 Conversely, butterflies are negatively affected by pesticides (Forister et al., 2016; Gilburn et
68 al., 2015). Provisioning nectariferous plants and reducing the use of pesticides are two
69 conservation actions with demonstrated benefits for butterflies in backyards (Fontaine et al.,
70 2016). Based on data from 2362 BCSP volunteers who participated two to eight years
71 between 2006 and 2013, we assessed how participation may foster pro-environmental
72 behaviors. We focused on two behaviors that have a direct impact on butterflies and
73 biodiversity, i.e., the provision of nectar resources and the use of pesticides in backyards.

74 Research in environmental psychology showed that the simple provision of
75 information is not enough, on its own, to induce behavioral changes (Byerly et al., 2018;

76 Osbaldiston and Schott, 2012; Schultz, 2011). However, more than simply receiving general
77 information about surrounding biodiversity and how to support it, volunteers in CS programs
78 live so-called “*experiences of nature*” (Clayton et al., 2017), with explicit attention to
79 biodiversity, that could facilitate pro-biodiversity practices (Prévot et al., 2018). We therefore
80 expected that participation would encourage volunteers to shift towards butterfly-friendly
81 gardening practices. Specifically, we hypothesized that sustained participation for multiple
82 years can lead to adopting the two studied pro-biodiversity practices (i.e., provisioning more
83 nectar resources and decreasing pesticide use). Additionally, within-year degree of
84 participation during the period of sustained engagement (Ponciano and Brasileiro, 2014) may
85 be seen as a quantitative measure of motivation for monitoring butterflies and we expected it
86 to be associated with higher provision of nectar resources and lower use of pesticides.

87 However, individual behavioral changes are constrained by a set of interacting factors,
88 such as attitudes, habits, personal capabilities, social norms, and context (Stern, 2000). In
89 particular, backyard’s management reflects the identity of its owners (e.g., interests and
90 activities such as recreation, eating, growing fruits or vegetables, connecting to nature;
91 Clayton, 2007). There is also evidence that personal experience and social norms can
92 influence practices (Ajzen, 1991; Goddard et al., 2013; Uren et al., 2015). For example,
93 gardeners from rural origins or inhabiting rural areas may use more pesticides in their
94 backyards compared with urban counterparts (Barrault, 2012; Coppin et al., 2002). Finally,
95 backyard management is also influenced by its size (Barrault, 2012; Clayton, 2007; Freeman
96 et al., 2012; Riboulot-Chetrit et al., 2018). Owners of large garden with a vegetable garden
97 and fruit trees may be particularly prone to using pesticides (Barrault, 2012). In our analyses,
98 we thus accounted for the role of backyard size and its position along an urbanization
99 gradient, as well as the presence of a vegetable garden or fruit trees in the backyard in
100 determining pro-biodiversity practices of volunteers. Specifically, we tested whether the latter

101 four variables could mediate the effect of sustained participation on the provisioning of nectar
102 resources or the use of pesticides by volunteers in their backyard.

103 Lastly, general attention towards environmental and biodiversity issues have gained
104 momentum in European countries (European Commission, 2013). These variations in
105 collective norms could be linked with potential changes in gardening practices. In this regard,
106 our study assesses across seven cohorts of volunteers (i.e., joining the BCSP program in seven
107 consecutive years) whether behavioral changes are associated to being involved in this nature-
108 focused CS program, strengthening our confidence that any observed pattern may not be
109 confounded with temporal changes occurring in the overall French population.

110

111

112 **2. MATERIALS and METHODS**

113 2.1 Data collection and localization

114 The Opération Papillons - Vigie-Nature (hereafter “BCSP”: Butterfly citizen science
115 project database for France; Noé - Muséum national d'Histoire naturelle, Paris, France;
116 <https://www.sciences-participatives-au-jardin.org/>) is a citizen science program in which
117 volunteers record butterflies in their backyard following a simple protocol (Fontaine et al.,
118 2016). Upon registration, volunteers give their consent that the data they provide can be used
119 for scientific studies. The program is open to the general public with no entomological skills
120 required, as butterfly identification is based on a closed list of 28 species/group of species.
121 Each year from March to October, volunteers identify and count butterflies in their backyard
122 and are invited to upload monthly lists of butterfly species abundance. Within a month, no
123 minimum amount of time of observations is required (but participants qualitatively report
124 their frequency of observations). In average, volunteers participated (i.e., uploaded butterfly
125 counts) 4.98 months annually (SE = 0.04 months, min. = 1, max. = 8). To motivate

126 volunteers, a monthly newsletter reported on overall participation, highlighted a ‘Butterfly of
127 the month’, and shared results of the project; additionally, a ‘tip of the month’ and a ‘plant of
128 the month’ sections could suggest pro-environmental behaviors (e.g., traditional crop varieties
129 may better tolerate pests and reduce the need for pesticides).

130 We used data from the first eight years of the program (2006-2013). We reduced our
131 dataset to volunteers who uploaded butterfly counts (i.e., participated) for several consecutive
132 years, the minimum being two years (regardless the number of months of participation per
133 year). Some volunteers interrupted their participation for one or several years. Because we
134 wanted to assess potential effects of sustained (i.e., continuous) involvement into the BCSP
135 program, we further restrained our dataset to volunteers with no annual break in participation.

136 Upon registration, participants provided the size of their backyard as well as its
137 localization (the municipality - smallest administrative district in France). Backyard size
138 ranged from 20 m² to 6000 m² (median = 1000 m², Q1 = 600 m², Q3 = 2000 m²). We
139 characterized urbanization context of each backyard by computing the percentage of urban
140 land use in the municipality (using “Artificial surfaces” from the first level of the Corine Land
141 Cover 2006 database; Bossard et al., 2006); it ranged from 0% to 100% (median = 7%, Q1 =
142 2%, Q3 = 26%). While backyard size and urbanization context were slightly correlated
143 (Kendall’s rank correlation $\tau = -0.33$, $P < 0.001$), there was no worrisome collinearity that
144 would prevent their inclusion in the same statistical model (see 2.3 and computations of
145 variance inflation factors). Participants also declared the presence of a vegetable garden or of
146 fruit trees.

147

148 2.2 Volunteers’ pro-biodiversity gardening practices

149 Participants were annually asked to fill out a questionnaire regarding the presence of
150 some specific backyard features and plants, from a closed list, as well as their use of

151 pesticides. None of the backyard features, plants, or level of pesticide use was a requirement
152 to participate. Based on this information, we computed the two following indices: nectar
153 resources, and pesticide use.

154 We used Bergerot and colleagues' (2010) ranking of plant attractiveness for butterflies
155 (related to nectar production) to compute the index of nectar resources in the backyard as
156 following: the presence of butterfly bushes (*Buddleja* spp.), knapweeds (*Centaurea* spp.),
157 lavenders (*Lavandula* spp.) or brambles (*Rubus* spp.) was scored 3 for each taxon; the
158 presence of valerians (*Valeriana* spp.), clovers (*Trifolium* spp.) or aromatic plants (e.g.,
159 *Rosmarinus officinalis*/spp., *Thymus* spp.) was scored 2 for each; the presence of geraniums
160 (*Pelargonium* spp.) was scored 1. The final index was computed by summing all these scores
161 (range: 0-19). All plants are common backyard species across the bioclimatic regions of
162 France.

163 The questions regarding pesticide use in the backyard varied in the period of the study.
164 From 2006 to 2009, we asked '*Is your garden treated with pesticides (e.g., insecticides, ant-*
165 *killers, aphid-killers or fungicides)?*' and volunteers could answer '*Never*', '*Occasionally*', or
166 '*Regularly*'. After 2009, this question was split into 5 more-detailed questions: 1) '*Are you*
167 *using insecticides?*', 2) '*[...] herbicides?*', 3) '*[...] fungicides?*', 4) '*[...] slug pellets?*', and 5)
168 '*[...] Bordeaux mixture?*' (the latter is a fungicide authorized in organic agriculture); again,
169 volunteers could answer '*Never*', '*Occasionally*', or '*Regularly*' to each of these questions.
170 Because the answer '*Regularly*' was rarely ticked (2.17%), we converted responses as binary
171 variables (0 – '*Never*', 1 – '*Occasionally*' or '*Regularly*'). To obtain for the whole 2006-2013
172 period a consistent index of pesticide use within backyards, we lumped responses to the 5
173 questions asked after 2009 into a single one: 0 – '*Never*' answered to each question, 1 –
174 '*Occasionally*' or '*Regularly*' answered to at least one question.

175 Some volunteers did not fill this questionnaire every year, in which case one or both
176 indices could not be computed for a given year. We therefore further restricted our dataset to
177 volunteers that provided backyard information for at least two years, including the first year
178 of their participation to serve as a baseline against which changes in garden practices
179 following sustained participation could be assessed. Our final dataset included 2362
180 volunteers distributed across all mainland France (Fig. 1).

181

182 2.3 Statistical analyses

183 As there were multiple observations per volunteer, we relied on mixed-effects
184 modeling to assess whether volunteers' individual gardening practices (provision of nectar
185 resources and pesticide use) changed over time since the start of participation. All statistical
186 analyses were performed with R version 3.5.2 (R Core Team, 2018) and, in particular, R
187 package *lme4* (Bates et al., 2015). Volunteers were structured in seven cohorts corresponding
188 to their first year of participation (Fig. 1): 2006 (n = 767), 2007 (n = 722), 2008 (n = 355),
189 2009 (n = 97), 2010 (n = 130), 2011 (n = 144), or 2012 (n = 147).

190 The index of nectar resources displayed an approximately Gaussian distribution; thus,
191 although it could only take integer values between 0 and 19, we decided to include it as the
192 response variable of a linear-mixed effect model. Explanatory variables included the time (in
193 years) since a volunteer started participating (*sustained participation*), the mean number of
194 months of participation per year for each volunteer (*within-year participation*), the size of the
195 backyard (*backyard size*; log transformed to improve residuals behavior), the percentage of
196 urban land use in the volunteer's municipality (*urbanization context*), the presence of a
197 vegetable garden in the backyard (*vegetable garden*), and the presence of fruit trees in the
198 backyard (*fruit trees*). We further tested whether these four latter variables mediated the effect
199 of sustained participation on the index of nectar resources by including each in a two-way

200 interaction with ‘*sustained participation*’ in the model. We included the longitude and latitude
201 of volunteers’ municipality (its centroid) to account for potential spatial auto-correlation in
202 our dataset. There were multiple observations per volunteer (from two to eight), and
203 volunteers were clustered in seven cohorts (Fig. 1). We accounted for these dependences in
204 our dataset by including volunteers’ identification code, nested within cohorts, as a random
205 effect. Intercept and slope of ‘*sustained participation*’ was allowed to vary among volunteers
206 within cohorts [coded as $(1 + \textit{sustained participation} \mid \textit{cohort_ID} : \textit{volunteer_ID})$].
207 Additionally, to account for potential annual unmeasured variations (e.g., climate effects on
208 plant growth, newsletters’ content sent to volunteers, media coverage of biodiversity issues),
209 we also included year as a random effect on the intercept. We computed variance inflation
210 factors (Zuur et al., 2009) of all explanatory variables and found no evidence of collinearity
211 (all VIF values < 1.5). Assumptions of homoscedasticity and normality of residuals of the
212 model were met. Spatial independence of model residuals was confirmed graphically by
213 computing a variogram (Zuur et al., 2009). Two-way interactions which had no significant
214 effects ($P > 0.05$) were removed from the models to better interpret single effects. This
215 mixed-effect model was based on a sample size of 9009 observations from 2362 volunteers.

216 To investigate variations of pesticide use by volunteers in their backyard, we
217 performed a generalized linear mixed-effects model with a binomial family and a *logit* link.
218 The response variable was binary, corresponding to using pesticides (1) or not (0). We
219 accounted for the change in how information regarding pesticide use within backyards was
220 gathered and treated (see above Volunteers’ pro-biodiversity gardening practices) by
221 including the type of recorded information regarding pesticide use as a fixed effect (two
222 levels: *single question* and *five questions*). Other fixed effects were the same as in the linear
223 mixed-effects model presented above. Specifying the same random-effect structure as above
224 led to a singular model fit. To resolve this issue, we followed Bates and colleagues (2018) and

225 simplified the random effect structure by removing the effect of year on the intercept. There
226 was no collinearity among our explanatory variables (VIF values < 1.5) and spatial
227 independence of model residuals was confirmed with a variogram. Two-way interactions
228 which had no significant effects ($P > 0.05$) were removed from the model to better interpret
229 single effects. This mixed-effect model was based on a sample size of 8636 observations from
230 2362 volunteers; observations number differs from the nectar resources linear mixed-effects
231 model because volunteers were allowed to only partially fill in the backyard information
232 annual questionnaire. We carried out post-hoc analyses to further interpret how significant
233 effects of two interactions (*'sustained participation x vegetable garden'* and *'sustained*
234 *participation x fruit trees'*) affected pesticide use. Specifically, we ran separate generalized
235 linear mixed-effects models for volunteers with or without a vegetable garden (regardless the
236 presence of fruit trees) and with or without fruit trees (regardless the presence of a vegetable
237 garden).

238 Duration of sustained participation ranged from two to eight years and was unbalanced
239 (765 and 166 volunteers participated during two and eight years respectively; the median
240 sustained participation duration was three years). To ensure this would not lead to biased
241 estimates of the relationships between explanatory variables and gardening practices, we
242 performed a randomization procedure (Manly, 2006). First, we randomly sampled (with
243 replacement) 166 volunteers from each participation duration to generate a random dataset.
244 Second, we ran the mixed-effects models to this randomly sampled dataset, and repeated this
245 procedure over 1000 iterations. We then compared the observed estimates (from the observed
246 whole dataset) with the distribution expected with constant number of participants (166) per
247 sustained participation duration (obtained from the 1000 iterations). We concluded from this
248 procedure that results obtained from models using the observed (i.e., whole) dataset can be
249 trusted (Supporting Information).

250

251

252 **3. RESULTS**

253 Both indices of gardening practices significantly changed with sustained participation
254 (i.e., the time in years since entering the Butterfly citizen science project), and a set of other
255 explanatory variables had effects on their own or mediated participation effects (Table 1).

256

257 3.1 Nectar resources in backyards

258 The index of nectar resources significantly increased with sustained participation
259 (Fig. 2a), and we found no evidence that this effect was mediated by other backyard variables
260 (size, urbanization context, presence of a vegetable garden or fruit trees; Table 1). In average,
261 after eight years of participation, the index of nectar resources increased by 13.7%. Within-
262 year participation was also significantly positively associated with backyard nectar resources
263 (Fig. 2b), but its effect was relatively weak: for every additional month of participation, nectar
264 resources increased by 1%. Backyard size was strongly and positively correlated with nectar
265 resources (Fig. 2c), with the index of nectar resources increasing by 33% from 100 m² to
266 1000 m² and then heading toward a plateau. Increasing urbanization context was significantly
267 correlated with lower nectar resources in backyards (Fig. 2d). Finally, backyards that included
268 a vegetable garden or fruit trees were associated to higher provisioning of nectar resources
269 (Fig. 2e-f).

270

271 3.2 Pesticide use in backyards

272 The use of pesticides in backyards was significantly correlated with sustained
273 participation; however, this relationship depended on whether or not volunteers had a
274 vegetable garden or fruit trees in their backyard (Table 1).

275 Sustained participation was associated to lower use of pesticide by volunteers who did
276 not have a vegetable garden in their backyard, but this relationship was weaker for volunteers
277 tending a vegetable garden (Fig. 3a). Yet, post-hoc analyses detected significant effects of
278 sustained participation on pesticide use in volunteers without or with a vegetable garden
279 ($P = 0.005$ and $P < 0.001$ based on a sample size of 3052 and 5584 observations respectively).
280 After eight years of participation, the probability of pesticide use decreased by 78% and 23%
281 in volunteers without or with a vegetable garden respectively.

282 Similarly, sustained participation was associated with lower pesticide use by
283 volunteers who did not have fruit trees in their backyard, but this relationship was weaker in
284 volunteers having fruit trees (Fig. 3b). Post-hoc analyses revealed a significant relationship
285 between sustained participation and pesticide use by volunteers having fruit trees in their
286 backyard or not ($P < 0.001$ and $P = 0.010$ based on a sample size of 6824 and 1812
287 observations respectively). After eight years of participation, the probability of pesticide use
288 in volunteers without or with a vegetable garden decreased by 73% and 37% respectively.

289 Additionally, backyard size was associated to increased probability of using pesticides
290 (Fig. 3c). From a 100 m² to a 1000 m² backyard, probability of using pesticides increased by
291 28%.

292

293

294 **4. DISCUSSION**

295 Using temporal data on gardening practices from a nature-based citizen science
296 program, we provided strong evidence that shifts towards biodiversity-friendly gardening
297 practices may occur through CS volunteering. To our knowledge, this is the first time that an
298 assessment of whether participating in a nature-based CS programs is associated to the

299 implementation of pro-biodiversity actions is based on such a large number of volunteers,
300 surveyed annually over multiple years.

301 We found positive correlations between sustained participation and level of pro-
302 biodiversity practices, i.e. growing nectar-rich flowering plants and decreasing pesticide use.
303 This is consistent with previous results from Cosquer and colleagues (2012), who carried out
304 interviews of 30 volunteers from the same CS program. Similarly, a recent study reported that
305 95% of 139 volunteers from different butterfly CS programs across the United States declared
306 participating more in conservation actions since engaging in one of their program
307 (Lewandowski and Oberhauser, 2017). However, as these authors noted, volunteers could
308 have increased their involvement regardless of joining a CS program, following potential
309 changes in social norms regarding environmental and biodiversity issues. In this regard, an
310 additional strength of the evidence presented here relies in our dataset including seven cohorts
311 of volunteers joining the BCSP program in consecutive years (Fig. 1), and observed changes
312 in gardening practices can be attributed with greater confidence to joining this nature-based
313 CS program. Our quantitative and large-scale approach thus complements the existing body of
314 qualitative evidence (Cosquer et al., 2012; Lewandowski and Oberhauser, 2017), and allows
315 emphasizing that, beyond the acknowledged value for research in ecology, nature-based CS
316 can also directly enhance local conservation measures at potentially broad geographical scale.

317 Our analyses also highlighted the importance of other variables than participation in
318 affecting levels of pro-biodiversity practices. In particular, backyard size was the strongest
319 predictor of nectar resources provisioning and a substantial one of pesticide use. Interestingly,
320 backyard size had contrasting effects as larger backyards had higher nectar resources (i.e., a
321 pro-biodiversity practice), but owners used more pesticides (i.e., a detrimental practice for
322 biodiversity). Among the eight groups of plants used to calculate the nectar index, only two
323 are spontaneous, while the presence of the others depends on the gardener decision to plant

324 them. Such decision is most likely influenced by the physical constraints imposed by the size
325 of the backyard, limiting the space that can be dedicated to different activities. The reasons for
326 owners of larger backyards to harbor greater nectar resources cannot be determined from our
327 dataset, and the aesthetic value of flowers may be the prime motivation, more than promoting
328 biodiversity (Clayton, 2007). In line with this, greater pesticide use in large backyards
329 appeared to be mostly due to greater application of herbicides and Bordeaux mixture (2010-
330 2013 data from detailed pesticide use by volunteers), suggesting the will to maintain safety
331 and order by controlling unwanted vegetation (Clayton, 2007; Riboulot-Chetrit et al., 2018).

332 Whether a backyard was used to grow food had multiple effects on pro-biodiversity
333 practices implemented by volunteers. Greater amount of nectar resources was found in
334 backyards where a vegetable garden or fruit trees were present. This could be interpreted as a
335 way for gardeners to attract pollinators required for crop pollination [see for example (Torres
336 et al., 2017) in the context of community gardening], but it could simply be that gardeners
337 tending a vegetable garden or fruits trees enjoy growing plants and thus are more likely to
338 spend time planting different species; additional data would be needed to investigate this and
339 other motives that volunteers may have in the present case. Most importantly, the presence of
340 a vegetable garden or fruit trees in backyards weakened – but did not prevent – the reduction
341 in pesticide use associated to sustained participation. Greater use of pesticides by backyard
342 owners growing food had been found previously (Barrault, 2012); therefore, the fact that
343 participation to nature-based CS was able to prompt a reduction in using these chemicals in
344 such context is very promising. Indeed, while the ban on the domestic use of some pesticides
345 enforced in France since January 2019 should improve backyard quality for biodiversity,
346 routine-experience of nature as proposed by nature-based CS programs may help prevent
347 shifts towards pesticides considered as less harmful but that can still have detrimental

348 environmental effects (e.g., the Bordeaux mixture, used in organic agriculture and remaining
349 allowed for domestic use; Bourdais, 1999).

350 Studies based on self-reported data may be prone to the two following limits. First,
351 researchers may obtain more responses from a subset of highly motivated persons. In the
352 present study, we maximized the number of volunteers that we could consider in the analyses,
353 including every volunteer of the BCSP program participating for at least two consecutive
354 years and from whom we had received backyard information in at least the first year of
355 participation and another year. Additionally, we ran a randomization procedure to check that
356 the reduced number of long-term volunteers did not bias results from our mixed-effects
357 modeling (Supporting Information). Second, respondents may be biased in their reporting,
358 being influenced by what is thought of as socially desirable. In our case, the primary use of
359 the backyard data was not to study volunteers' actions or behaviors in their backyard but to
360 understand the influence of gardening practices on butterflies. This clearly advertised
361 biodiversity-focused objective may have prevented biased reporting due to social desirability.
362 Indeed, the reported data were used by Fontaine and colleagues (2016) who successfully
363 detected positive and negative effects of the index of nectar resources and pesticide use on
364 butterflies, respectively, as expected from the literature (Forister et al., 2016; Gilburn et al.,
365 2015; Luppi et al., 2018). Thus, while our dataset may not be exempt of bias, it likely well
366 describes practices in volunteers of the BCSP program.

367 Our findings confirmed that participation to nature-based CS program can prompt pro-
368 biodiversity practices in volunteers, with direct local benefits for conservation. An analysis of
369 interviews of 30 volunteers of the BCSP suggested that the development of awareness of
370 butterflies and understanding of their ecological needs led to the intentional implementation
371 of pro-conservation actions (Cosquer et al., 2012). Regular attentive observations of
372 butterflies for the program constituted routine experiences of nature that may have primed

373 volunteers towards adopting pro-biodiversity practices (Prévot et al. 2018, 2017). As
374 recommended elsewhere (Lewandowski and Oberhauser, 2017), we encouraged the adoption
375 of biodiversity-friendly gardening practices (through newsletters): this may have been
376 particularly effective in spurring changes in backyard management, because volunteers were
377 environmentally concerned and declared that '*helping biodiversity conservation*' was one of
378 their main reasons for participating (Cosquer et al., 2012; Prévot et al., 2017). It is also
379 possible that belonging to a community of observers (e.g., receiving newsletters, engaging in
380 a program led by the National Museum of Natural History and Noé, an environmental NGO)
381 has favored changes in attitudes and social norms towards greater acceptance of backyards
382 features benefitting butterflies. Last but not least, our results may be particularly expected
383 from a citizen science program engaging backyard owners. Indeed, volunteers managed their
384 backyard the way they chose, and perceived control to meet a particular outcome (i.e.,
385 perception of self-efficacy) was found to be positively associated with the probability to
386 engage into pro-environmental behaviors (Ajzen, 1991; Hines et al., 1987). Sustained
387 participation to a nature-based CS program may allow experiencing the causality between
388 practices and biodiversity outcomes (Cosquer et al., 2012), and the shift towards pro-
389 biodiversity behaviors would then be likely, thanks to high perceived control. Complementary
390 data would be required to understand how gardeners' experience, knowledge, resources, or
391 available time may influence behavioral changes in the context of participation in citizen
392 science.

393 Backyards hold great potential as '*pollinator hotspots*' in cities (Baldock et al., 2019;
394 Levé et al., 2018), and are thus of paramount importance for urban conservation strategies of
395 butterflies and the wider flower visitor fauna. Yet, improving their quality through
396 biodiversity-friendly management (e.g., planting nectar-rich or host plants, reducing mowing
397 frequency) will require wishful personal involvement from the owners. We highlighted the

398 roles of different factors in determining adoption of pro-biodiversity practices by citizen
399 scientists. This calls for collaborations between biologists and social scientists if we are to
400 succeed in further changing behaviors towards conservation goals (Schultz, 2011). Different
401 tools exist to favour pro-environmental changes, but uncertainties remain regarding their
402 efficiency under various conditions and for different behaviors (Byerly et al., 2018; Schultz,
403 2014). Beyond provisioning information and encouraging volunteers to engage in
404 conservation, biologists involved in nature-based CS programs should embrace collaborations
405 with psychological scientists to design and test interventions for enhancing adoption of pro-
406 biodiversity behaviors (Clayton et al., 2013). For example, by designing experimental emails
407 or newsletters, we could test the effectiveness of different strategies – such as Messenger
408 effect, Norms, or Saliency (Byerly et al., 2018) – in spurring behavioral changes in volunteers.
409 Given the tens of thousands of citizen scientists monitoring biodiversity in their backyards in
410 Europe and North America (Cannon et al., 2005; Lorrillière et al., 2018; Princé and
411 Zuckerberg, 2015), this exciting avenue of interdisciplinary research represents critical stakes
412 for biodiversity conservation in cities.

413

414

415 **SUPPORTING INFORMATION**

416 Methodological details and results of the randomization procedure are available online
417 (Appendix S1).

418

419

420 **ACKNOWLEDGMENTS**

421 We thank the thousands of volunteers of the Opération Papillons - Vigie Nature (2019)
422 program for their effort and time monitoring butterflies. We are grateful to the NGO Noé and

423 to the Vigie-Nature team for managing the citizen science program, to A-C Maurice and
424 members of the CESCO for fruitful methodological discussions, and to two anonymous
425 reviewers for helpful suggestions. ND was funded by the BiodivERsA3-2015-104
426 (BIOVEINS) grant, and KP was funded by the ANR-17-CE04-0012 (VGI4BIO). Funding
427 sources were not involved in any step of this study.

428

429

430 **AUTHORS CONTRIBUTIONS**

431 **Nicolas Deguines:** Conceptualization, Methodology, Formal Analysis, Visualization, Writing
432 - Original Draft, Writing - Reviewing and Editing.

433 **Karine Princé:** Conceptualization, Methodology, Writing - Reviewing and Editing.

434 **Anne-Caroline Prévot:** Conceptualization, Writing - Reviewing and Editing.

435 **Benoît Fontaine:** Conceptualization, Data Curation, Methodology, Writing - Reviewing and
436 Editing, Monitoring Scheme Management.

437

438

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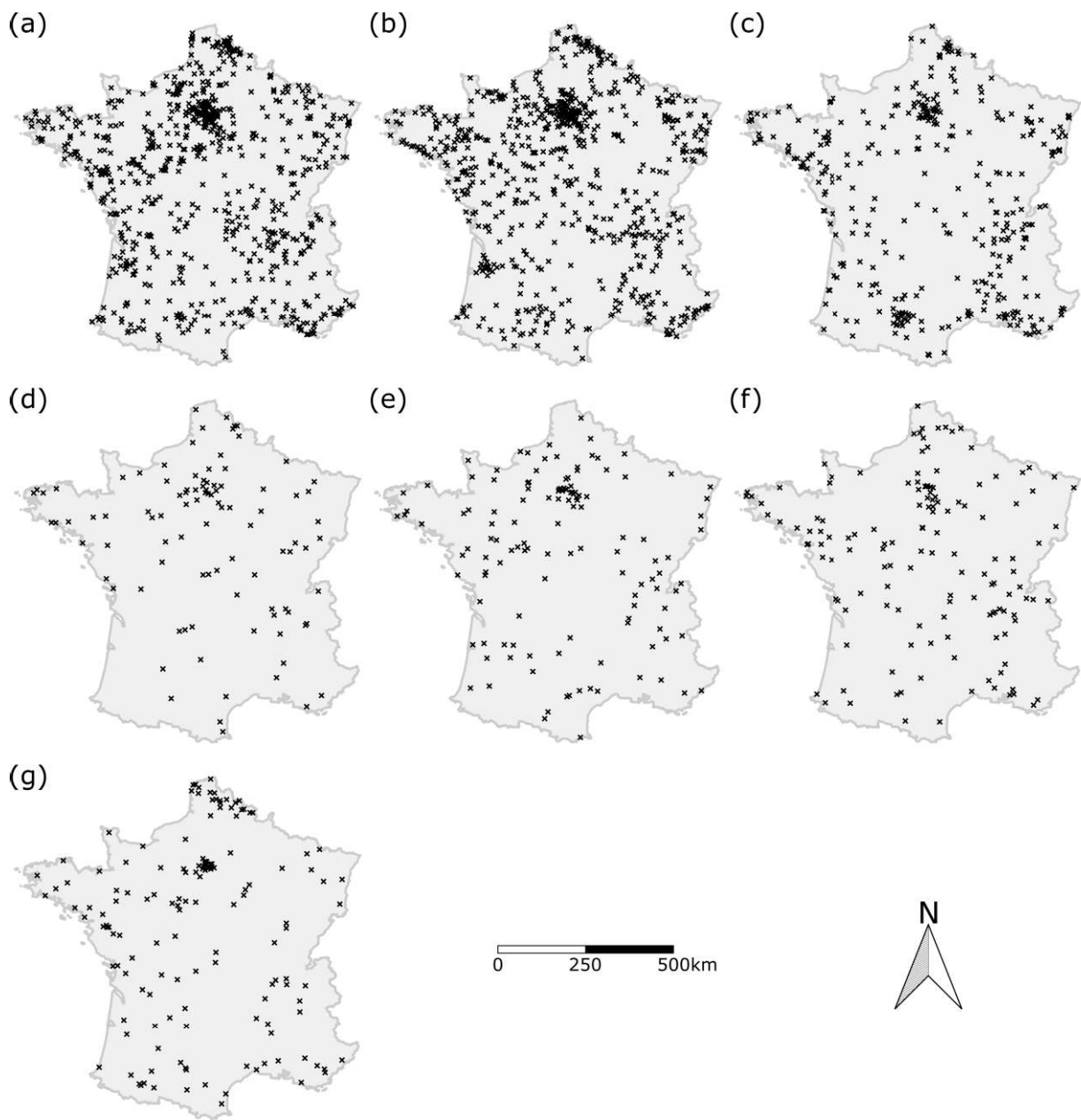
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642
643

644 **Table 1: Results from final mixed-effects models.** Predictors' estimates are shown for the
645 linear mixed-effects model (Nectar resources) and the generalized linear mixed-effects model
646 (Pesticide use), along with their associated 95% confidence intervals, and *P*-values. *Sust.*
647 *participation*, *Urban. cont.*, *Pres. veg. garden*, and *Pres. fruit trees* stand for sustained
648 participation, urbanization context, presence of a vegetable garden within the backyard (vs
649 absence), and presence of fruit trees within the backyard (vs absence) respectively. Two-way
650 interactions associated to a *P*-value > 0.05 were sequentially removed from the complete
651 models (see 2.3).

Response variable	Explanatory variable	Estimate	Lower CI	Upper CI	<i>p</i>
Nectar resources	Sust. participation	0.200	0.125	0.275	<0.001
	Within-year participation	0.117	0.043	0.190	0.002
	Backyard size	1.235	1.085	1.385	<0.001
	Urban. cont.	-0.012	-0.018	-0.006	<0.001
	Pres. veg. garden	0.566	0.379	0.753	<0.001
	Pres. fruit trees	0.783	0.572	0.994	<0.001
	Longitude	0.049	-0.004	0.101	0.068
	Latitude	0.083	0.012	0.153	0.022
	Sust. participation x Backyard size	-	-	-	-
	Sust. participation x Urban. cont.	-	-	-	-
	Sust. participation x Pres. veg. garden	-	-	-	-
	Sust. participation x Pres. fruit trees	-	-	-	-
	Pesticide use	Sust. participation	-0.501	-0.659	-0.343
Within-year participation		0.075	-0.028	0.178	0.156
Backyard size		0.229	0.022	0.436	0.030
Urban. cont.		0.007	-0.002	0.015	0.127
Pres. veg. garden		-0.285	-0.809	0.240	0.288
Pres. fruit trees		0.028	-0.597	0.653	0.930
Longitude		0.077	0.007	0.148	0.032
Latitude		-0.046	-0.142	0.049	0.342
Type of pesticide use information		3.793	3.470	4.116	<0.001
Sust. participation x Backyard size		-	-	-	-
Sust. participation x Urban. cont.		-	-	-	-
Sust. participation x Pres. veg. garden		0.270	0.135	0.406	<0.001
Sust. participation x Pres. fruit trees		0.160	0.002	0.317	0.047

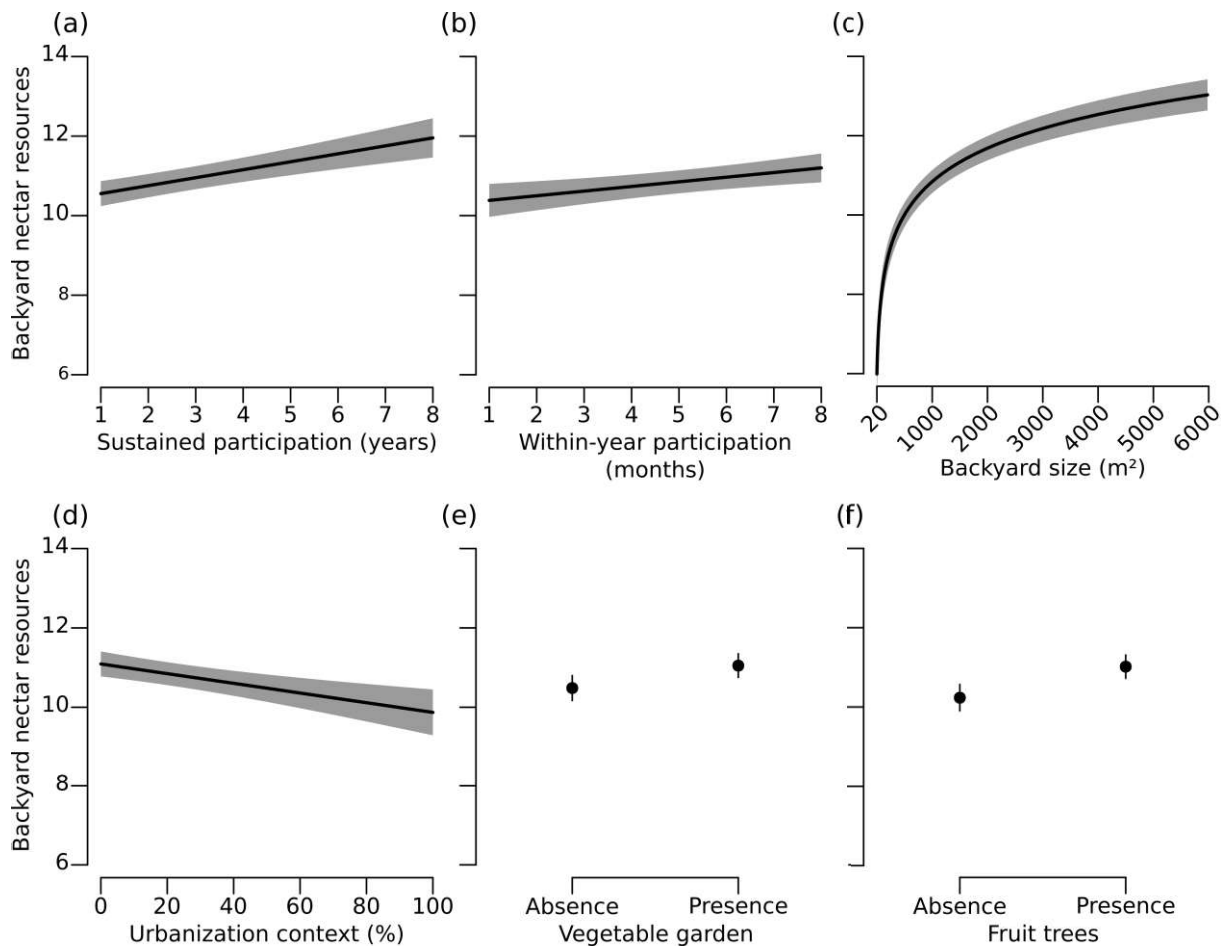
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655

656 **Figure 1. Localization of the 2362 backyards.** From (a) to (g), volunteers joining the
 657 Butterfly citizen science project in 2006 (n = 767), 2007 (n = 722), 2008 (n = 355), 2009 (n =
 658 97), 2010 (n = 130), 2011 (n = 144), and 2012 (n = 147) respectively.



660

661 **Figure 2. Predictors of backyard nectar resources.** Effect of (a) sustained participation, (b)662 within-year participation, (c) backyard size (back-transformed in m²), (d) backyard

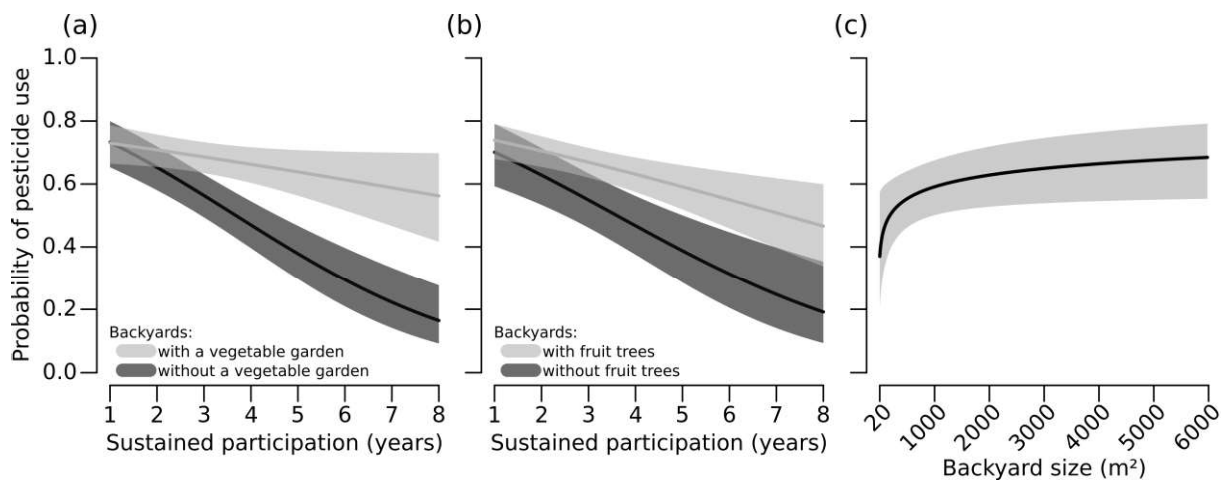
663 urbanization context (percentage of urban areas in backyard's municipality), (e) presence of a

664 vegetable garden within the backyard, and (f) presence of fruit trees within the backyard. In

665 (a-d), lines are predictions from the linear mixed-effects model and grey bands are associated

666 95% confidence intervals. In (e) and (f), bars represent 95% confidence intervals.

667



668

669 **Figure 3. Predictors of pesticide use in backyards.** Effect of (a) the interaction between
670 sustained participation and presence of a vegetable garden within the backyard, (b) the
671 interaction between sustained participation and presence of fruit trees within the backyard,
672 and (c) backyard size (back-transformed in m²). Lines are predictions from the generalized
673 mixed-effects model, and grey bands are associated 95% confidence intervals.

1 **Table 1: Results from final mixed-effects models.** Predictors' estimates are shown for the
 2 linear mixed-effects model (Nectar resources) and the generalized linear mixed-effects model
 3 (Pesticide use), along with their associated 95% confidence intervals, and *P*-values. *Sust.*
 4 *participation*, *Urban. cont.*, *Pres. veg. garden*, and *Pres. fruit trees* stand for sustained
 5 participation, urbanization context, presence of a vegetable garden within the backyard (vs
 6 absence), and presence of fruit trees within the backyard (vs absence) respectively. Two-way
 7 interactions associated to a *P*-value > 0.05 were sequentially removed from the complete
 8 models (see 2.3).

Response variable	Explanatory variable	Estimate	Lower CI	Upper CI	<i>p</i>
Nectar resources	Sust. participation	0.200	0.125	0.275	<0.001
	Within-year participation	0.117	0.043	0.190	0.002
	Backyard size	1.235	1.085	1.385	<0.001
	Urban. cont.	-0.012	-0.018	-0.006	<0.001
	Pres. veg. garden	0.566	0.379	0.753	<0.001
	Pres. fruit trees	0.783	0.572	0.994	<0.001
	Longitude	0.049	-0.004	0.101	0.068
	Latitude	0.083	0.012	0.153	0.022
	Sust. participation x Backyard size	-	-	-	-
	Sust. participation x Urban. cont.	-	-	-	-
	Sust. participation x Pres. veg. garden	-	-	-	-
	Sust. participation x Pres. fruit trees	-	-	-	-
	Pesticide use	Sust. participation	-0.501	-0.659	-0.343
Within-year participation		0.075	-0.028	0.178	0.156
Backyard size		0.229	0.022	0.436	0.030
Urban. cont.		0.007	-0.002	0.015	0.127
Pres. veg. garden		-0.285	-0.809	0.240	0.288
Pres. fruit trees		0.028	-0.597	0.653	0.930
Longitude		0.077	0.007	0.148	0.032
Latitude		-0.046	-0.142	0.049	0.342
Type of pesticide use information		3.793	3.470	4.116	<0.001
Sust. participation x Backyard size		-	-	-	-
Sust. participation x Urban. cont.		-	-	-	-
Sust. participation x Pres. veg. garden		0.270	0.135	0.406	<0.001
Sust. participation x Pres. fruit trees		0.160	0.002	0.317	0.047

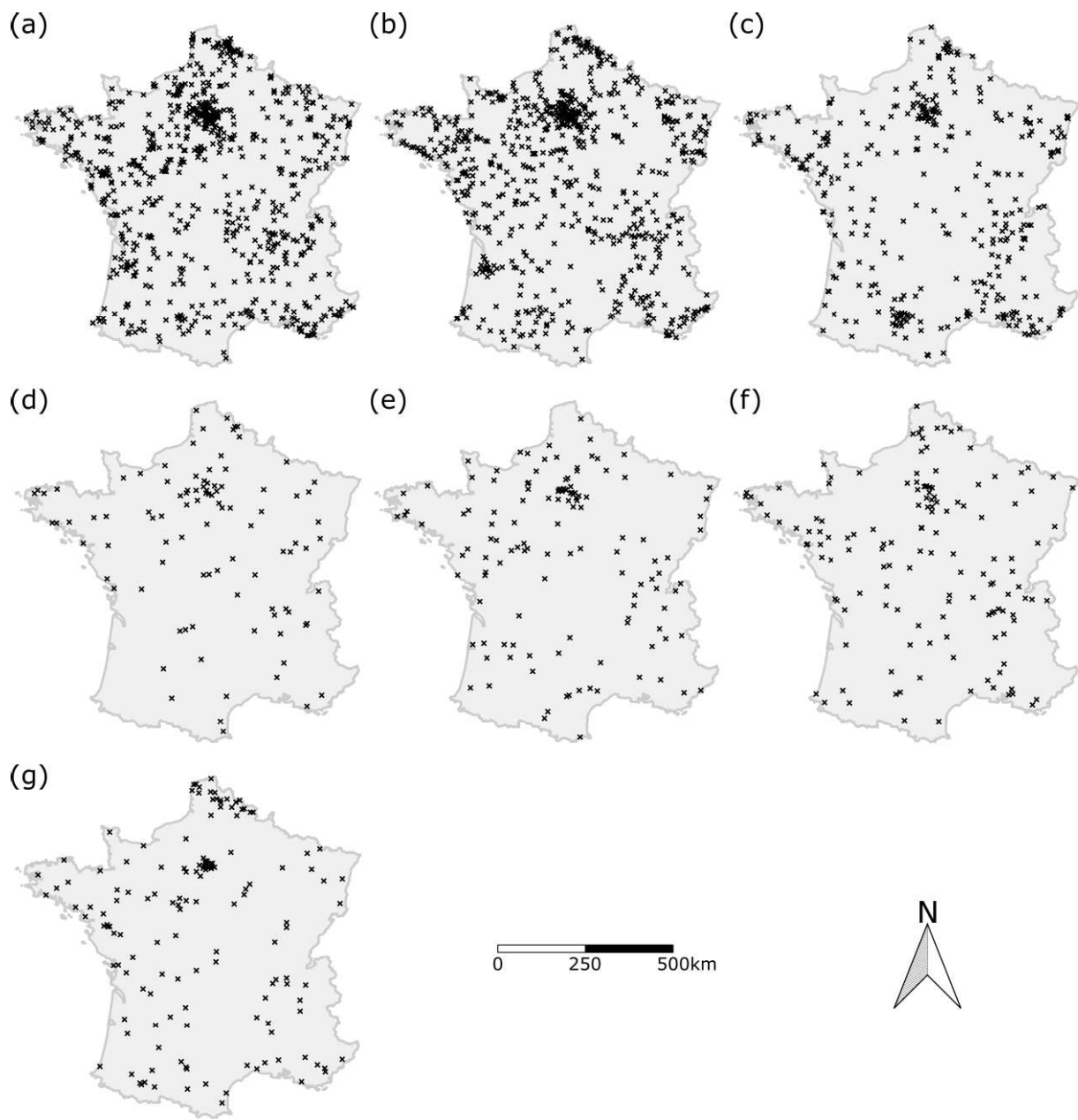
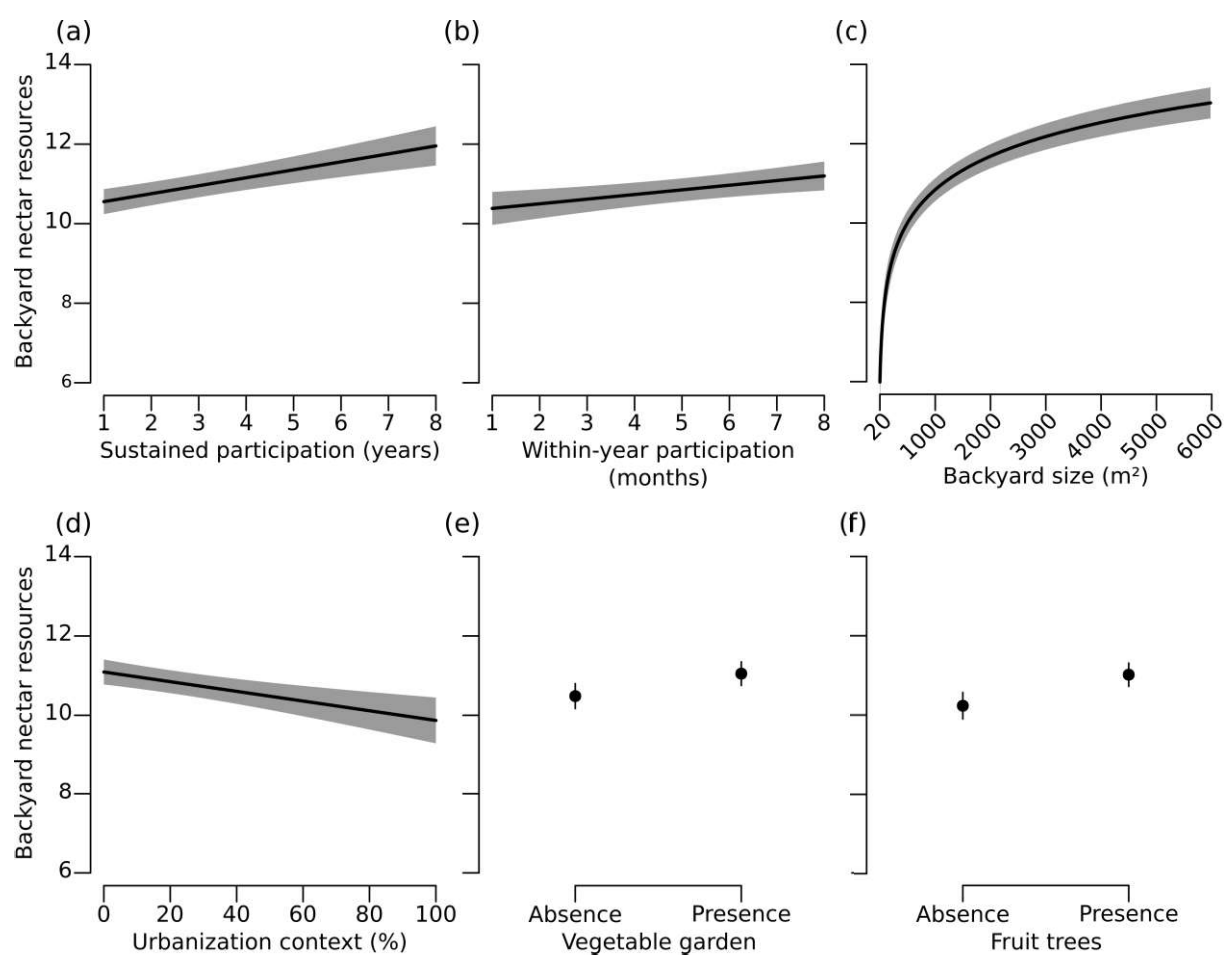
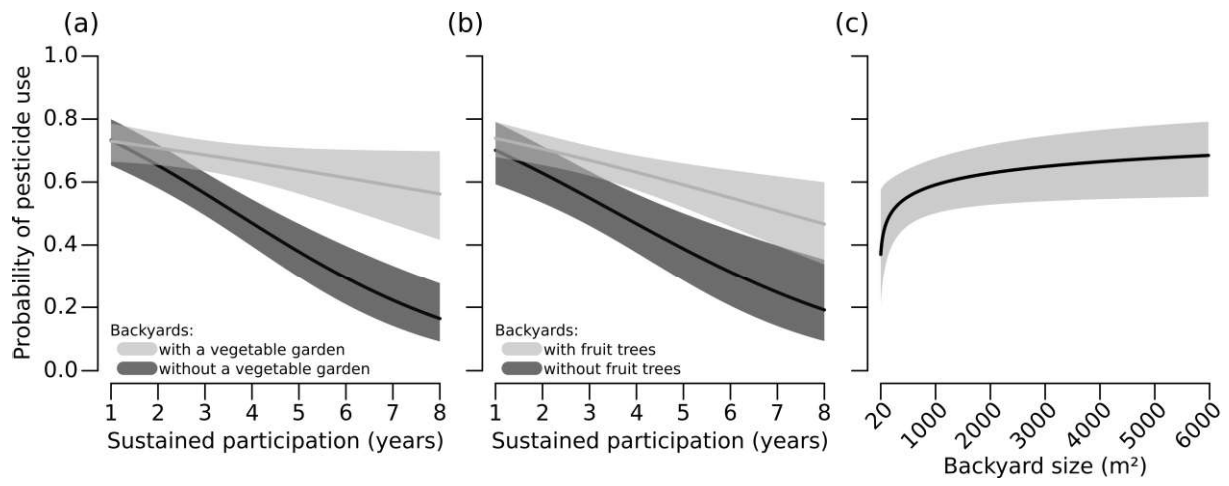


Figure2

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