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## Organic farming positively affects the vitality of passerine birds in agricultural landscapes.

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20 **Abstract**

21 Conventional farming has been implicated in global biodiversity loss, with many farmland  
22 birds in decline. Organic farming is often considered a more ecological alternative since it  
23 generally hosts greater faunal diversity. To date, the impact of conventional agriculture on the  
24 decline in avian species has mainly been assessed through the lens of biodiversity loss; few  
25 studies have examined the effects of conventional farming on individual life-history trait  
26 components. Behaviour represents the final integrated outcome of a range of biochemical  
27 and physiological pathways and can be considered a proxy of health as it is more sensitive  
28 than other life-history traits, potentially allowing environmental changes to be better tracked.  
29 The goal of this study was to understand how exposure to conventional versus organic  
30 farming affects the behaviour of passerine birds in real conditions. By sampling 6 species of  
31 passerine birds in 10 hedgerows in organic landscapes and 10 hedgerows in conventional  
32 landscapes during the breeding period, we found evidence that organic farming sharply  
33 increased the vitality of individuals, irrespective of species. This was measured through  
34 behaviour such as flee attempts, aggressivity, pecking and distress calls when captured, all of  
35 which were higher in birds caught in organic hedges than those caught in conventional  
36 landscapes. We posit that passerines living in organically farmed landscapes benefit from  
37 reduced pesticide exposure rather than a greater abundance of food, as body condition was  
38 identical in the two contexts. These findings suggest that the behaviour of passerines can be a  
39 useful indicator of the state of the environment and can thus serve as an early warning of  
40 specific environmental change in agricultural areas. Further studies assessing the life-history  
41 traits of farmland birds may be a valuable aid to understanding the impact of conventional  
42 agriculture on biodiversity.

43

- 44 **Keywords:** agricultural intensification, behaviour, conventional farming, organic farming,
- 45 passerine birds, pesticides

## 46 **1. Introduction**

47 Over the last half-century, the challenge of feeding a growing human population has led to  
48 agricultural intensification that aims to maximize productivity, a process characterized by the  
49 improvement of crop varieties, the replacement of habitat heterogeneity by vast monocultures,  
50 and the increased use of agrochemical compounds such as non-organic fertilizers and  
51 pesticides (Zhang et al., 2013; Robertson et al., 2014). In the same time, unprecedented  
52 biodiversity declines were demonstrated in intensive agrosystems, raising concerns about the  
53 sustainability of such farming systems (Chamberlain et al., 2000; Stoate et al., 2009). Much  
54 literature has been produced on the processes affecting farmland birds (e.g., decreased food  
55 availability and suitable habitats, pesticide poisoning, mortality due to harvesting), but only a  
56 set of farmland species were investigated (Robinson and Sutherland, 2002; Geiger et al.,  
57 2010; Mitra et al., 2011; Mineau and Whiteside, 2013; Chiron et al., 2014; Stanton et al.,  
58 2018). Organic agriculture, which combines traditional farming methods with modern  
59 technology, has been put forward as an alternative to conventional farming, offering improved  
60 sustainability in food production both in terms of biodiversity and human health (Sandhu et  
61 al., 2010; Seufert et al., 2012; Gonthier et al., 2014). Indeed, higher bird density and species  
62 richness in organic compared to conventional farms were almost invariably found so far  
63 (Fluetsch and Sparling, 1991; McKenzie and Whittingham, 2009; Mondelaers et al., 2009;  
64 Batary et al., 2010; Chamberlain et al., 2010; Smith et al., 2010; Tuck et al., 2014; Stanton et  
65 al., 2018; Gregory et al., 2019; Moreau et al., 2021).

66 However, this clear difference between conventional and organic farming on birds has  
67 been assessed almost exclusively using species richness metrics (Robinson and Sutherland,  
68 2002; Geiger et al., 2010; Mitra et al., 2011; Mineau and Whiteside, 2013; Chiron et al., 2014;  
69 Stanton et al., 2018), while the impact of these two types of farming on individual life-history  
70 traits has been very little studied. The positive effects on bird species of organic compared to

71 conventional agriculture may result from different factors, such as improved food resources  
72 and/or higher availability of nesting sites (e.g., grasslands or hedges). Organic farming  
73 landscapes tend to have higher crop diversity, higher plant and faunal diversity, larger areas of  
74 semi-natural elements and, more generally, higher landscape diversity (Hole et al., 2005;  
75 Tuck et al., 2014; Reganold and Watcher, 2016; Gibson et al., 2007). These features allow  
76 improved foraging and nesting opportunities for insects (Tuck et al., 2014), hence more  
77 resources for birds. In addition, lower pesticide exposure is expected in organic landscapes,  
78 either directly (through contact) or indirectly (through consumption of food). While the intake  
79 of large quantities of pesticides can be lethal for wild individuals, chronic exposure to smaller  
80 amounts could also have sublethal effects on wild populations. Numerous laboratory  
81 experiments, as well as some field studies, have detailed the toxic effects of pesticides on  
82 birds' life-history traits, which ultimately decrease their survival (Mitra et al., 2011; Lopez-  
83 Antia et al., 2015; Millot et al., 2017; Moreau et al., 2021). However, only a handful of  
84 studies have investigated the effects of conventional farming on individual life-history traits,  
85 and these only concern grassland birds (Hole et al., 2002; Baeta et al., 2012). To improve our  
86 knowledge of the effects of the farming environment on birds, our aim was to compare a suite  
87 of behavioural traits in birds living in conventional versus organic farming landscapes.

88 An organism's behaviour represents the final integrated outcome of a range of  
89 biochemical and physiological processes (Odum, 1971) and may be considered as a proxy  
90 of individual health that is more sensitive to stress than survival or other physiological  
91 measures (Clotfelter et al., 2004; Hellou, 2011). Numerous chemicals are known to  
92 interfere with the endocrine system of animals (Toppari et al., 1996), and individuals are  
93 often exposed to multiple chemicals in their environment that can accumulate in body  
94 tissue. Subtle alterations in behaviour may be manifested below lethal toxicity levels and can  
95 thus be regarded as sensitive toxic response indicators (Hellou, 2011). Yet behavioural

96 alteration has been largely unexploited by ecotoxicologists despite the fact that behaviour is  
97 considered to be 10 to 1000 times more sensitive than the conventional LD50 value (LD  
98 stands for "Lethal Dose" corresponding to the amount of a pesticide, given all at once, which  
99 causes the death of 50% of a group of test animals) of acute toxicity used in ecotoxicity tests,  
100 and thus could be considered an early warning signal to assess environmental quality  
101 (Dell’Omo, 2002; Hellou et al., 2008). **In addition, behavioral monitoring can be a relatively**  
102 **fast, simple and non-invasive approach to quantify individual responses in the field (Peakall,**  
103 **1985).** For example, behavioural traits in passerine birds have been extensively used as a  
104 biomonitoring tool to measure the effects of urbanization (Albarayak and Mor, 2011).  
105 ~~though behavioural monitoring is not always feasible as it is often necessary to capture~~  
106 ~~individuals to assess properly their behaviour.~~

107 Many farmland birds nest in hedgerows, but forage either in hedgerows or adjacent  
108 fields, depending on the species and the crop (Birds of the World, 2022). Common passerine  
109 species have small home ranges, therefore, the type of farming system surrounding the  
110 hedgerow (i.e., organic or conventional) allows the comparison of their living environment  
111 and their core home range. To investigate this, we selected a sample of hedgerows with  
112 different farming systems operating in the surrounding fields, organic and conventional,  
113 keeping all other parameters (e.g., hedgerow type, crop type) as constant as possible to isolate  
114 the effects of ‘organic’ *versus* ‘conventional’ landscapes. We then monitored the behaviour  
115 of 6 species of passerine birds belonging to different families that breed in these hedgerows,  
116 to measure a suite of behaviours in individuals from the same species sampled in organic  
117 landscapes or in conventional landscapes. **We expect that birds captured in organic farming**  
118 **have a better health condition and consequently more vigorous behavioral responses than**  
119 **birds captured in conventional farming.**

120

## 121 2. Material and methods

122 **2.1 Experimental design.** The study was conducted in the ‘Zone Atelier Plaine & Val de  
123 Sèvre’ (ZA-PVS), a 435 km<sup>2</sup> Long-Term Social-Ecological Research (LTSER) site in central-  
124 western France (46°23’N, 0°41’W). The site consists largely of agricultural land, with urban  
125 areas making up 9.8% of the area and fragmented woodlands 3.1%. It is bordered in the north  
126 by the city of Niort and in the south by Chizé forest (see Bretagnolle et al. 2018). The  
127 majority of the area is typical intensive farmland, made up of open landscapes with mainly  
128 winter cereals and other arable crops (maize, sunflower, oilseed rape, pea), temporary  
129 grasslands (such as alfalfa and clover) and permanent meadows. The site has a rather high  
130 diversity of types of farming system, with ~15 farms managed using conservation agriculture  
131 practices, ~60 farms using organic methods, and 350 using conventional methods, of which  
132 about 50% are mixed dairy/cereal farms. Agricultural land use within the site has been  
133 monitored annually at the field scale since 1994 and mapped on vector-based shapefiles  
134 (Bretagnolle et al., 2018). Every organically farmed field is identified (see Wintermantel et  
135 al., 2019), providing a very detailed description of farming practices regarding pesticide use at  
136 field (organic versus conventional farming) and landscape scales. On average, conventional  
137 farmers use 5-10 different pesticide molecules on their fields (in c. 4-8 applications per year;  
138 Bretagnolle and Gaba unpublished data), while organic farmers use none. ~~Unfortunately, for  
139 the moment, we do not have information on the types of molecules applied and the frequency  
140 of treatments by farmers in conventional agriculture.~~

141 We used this detailed knowledge to select 10 hedgerows surrounded by organically  
142 farmed landscapes and 10 hedgerows surrounded by conventionally farmed landscapes, each  
143 with a 250-m radius buffer zone. The percentage of organic farming was calculated within  
144 this 250-m radius buffer. We chose this buffer-zone size to include the breeding home-range  
145 size for different passerine species (see below). For hedgerows defined as ‘organic hedges’,



146 73% to 98% of the buffer area was organically farmed, while ‘conventional hedges’ had  
147 almost no organic farming within the buffer area (see Table 1).

148 Since hedgerows in the two landscape types may differ for other reasons than just the  
149 type of agricultural system, we measured several descriptive parameters for each, including  
150 total hedgerow length (m), hedgerow height (m), top width at 3 m above ground and bottom  
151 width (m), and the approximate length of holes, gaps or clearings within the hedgerow (m).  
152 Length and width were estimated using a measuring tape. We estimated hedgerow height and  
153 top and bottom width by averaging measurements made at ten different points randomly  
154 chosen along the hedgerow (see Arnold, 1983; Green et al., 1994; MacDonald and Johnson,  
155 1995 for exact procedures). We also estimated the length of wooded and shrubby layers in the  
156 hedgerow at ground level using a measuring tape. A tree was considered mature (wooded  
157 layer) if its diameter at breast height was  $> 10$  cm. To assess the density of the hedgerow, at  
158 10 random points along it we pushed a thin rod through the hedge at 1 m above the ground,  
159 then counted the number of contacts between the rod and branches.

160 In addition, at a larger spatial scale, we recorded the surface area of woods in the  
161 vicinity of a hedgerow within a 250-m radius and the dominant type of cultivation. None of  
162 the parameters measured for the 20 hedgerows differed significantly between the two types of  
163 agricultural systems (see Table 1), except the % of organic farming within the 250-m radius  
164 buffers.

165

166 **2.2 Bird captures.** The same net-trapping method was used in each hedgerow to catch birds  
167 from sunrise (between 6:00 am and 7:00 am depending on the month) to 11:00 am, during the  
168 breeding season, from mid-April to the end of June 2019. Before sunrise, 10 identical 12-m  
169 long mist nets were spread alongside the hedges of a given selected site. Nets were monitored  
170 every 5 to 10 minutes to check if a bird was caught to ensure birds did not remain in the net

171 for more than 10 minutes. Each hedge was sampled three times (only one hedge per day) to  
172 cover the full breeding season, first from 15/04 to 05/05, then from 07/05 to 29/05, and finally  
173 from 01/06 to 23/06. Mist nets were set only when the meteorological conditions were  
174 favourable (no wind, no rain, and temperature above 8°C at sunrise). At each capture, the  
175 ambient temperature in the shade of the hedge and the time were recorded.

176 A total of 17 species were caught, of which the six most common became the focus of  
177 the study. The six most abundant passerines were the Eurasian black cap (*Sylvia atricapilla*, N  
178 = 46), ciril bunting (*Emberiza cirilus*, N = 31), common nightingale (*Luscinia megarhynchos*,  
179 N = 26), great tit (*Parus major*, N = 21), common whitethroat (*Sylvia communis*, N = 21) and  
180 melodious warbler (*Hippolais polyglotta*, N = 19). All other species were excluded from the  
181 analysis due to the low number of individuals (<10) caught, precluding statistical analyses.  
182 During breeding, the home range sizes for these different species range from 0.2 ha to 8 ha  
183 (Moskat et al., 1993; Naef-Daenzer, 1994; Stoated and Szczur, 2001; Naguib et al., 2001;  
184 Halupka et al., 2002; Stevens et al., 2002; Assandri et al., 2017), corresponding to a radius  
185 around the edge from 25 to 160 m. These breeding home-range sizes are therefore smaller  
186 than the size of our study plots (buffer size of 250-m radius). Given that passerine home range  
187 sizes are small (1-2 ha) during the breeding period and certainly smaller than disk sizes (12-  
188 15ha) on which the proportion of organic/conventional farming systems were estimated  
189 around hedges, we assume that most time spent by an individual bird was restricted to the  
190 targeted area. Small breeding home-range sizes and site fidelity were confirmed by recapture  
191 rates (e.g., 45 birds were recaptured in the very same hedgerow). **To avoid pseudo replication,**  
192 **if a bird was recaptured, it has been immediately released without making measurements.**  
193 **Only its first capture with the data appears in the database.**

194

195 **2.3. Behavioural parameters.** For every bird caught, we recorded several types of behaviour  
196 (see details and references for procedures below). The behaviour of each bird was always  
197 recorded by a unique observer, within 10 min after capture. Each procedure was performed in  
198 the same sequential order to measure: (i) escape vigour, (ii) breath rate, (iii) aggressivity, (iv)  
199 handling vigour (during morphological measurement), and (v) tonic immobility. After the full  
200 set of measurements and ringing, all birds were released at the site of capture. None of the 164  
201 birds caught was injured or died during the experiments.

202

### 203 *2.3.1. Escape vigour (flee attempts from mist net)*

204 To assess the vigour of a bird captured in the net, we developed an original protocol. Once a  
205 bird was caught in the mist net, escape vigour was estimated in two steps using a standardized  
206 procedure. First, we approached the mist net slowly and, once the bird detected the ringer  
207 (i.e., when it tried to flee), we counted the number of flee attempts for 15 seconds while  
208 continuing to walk slowly towards the bird. Second, when near the bird, the experimenter  
209 reached one hand out at a distance of 5 cm from the bird's head, opening the hand slowly ten  
210 times to record the number of flight attempts. As these two escape metrics were highly  
211 correlated for each species (Spearman rho > 0.46, P < 0.0001), we summed them to get an  
212 overall score of escape vigour. In the rare cases in which two birds were caught at the same  
213 time in a net (less than 2% of total individuals caught), these individuals were excluded from  
214 the analysis. After these measurements, all captured birds were put singly in a bag for 10 min.

215 We expected that the number of flee would be higher for the birds caught in organic farming  
216 because they can afford such energetic cost by living in food-rich environments, and because  
217 they would need less energy for pesticide detoxification processes (Lushchak et al., 2018;  
218 Wiegand, 2019). Hence these birds would be more vigorous and reactive to escape a possible  
219 predator.

220

### 221 2.3.2. *Breath rate*

222 After 10 min in the bag, the bird's breath rate was measured to estimate the degree of acute  
223 physiological stress experienced during handling (Carere and van Oers, 2004; Markó et al.,  
224 2013; Rabdeau et al., 2019). The bird was first taken out of the bag, then the number of breast  
225 respiratory movements was counted for 30 seconds while holding the wings fixed (Markó et  
226 al., 2013; Torné-Noguera et al., 2014). We expected the breath rate to be higher for the birds  
227 caught in conventional farming due to the chronic stress of living in such environment (less  
228 abundant food, presence of pesticide, etc.)

229

### 230 2.3.3. *Aggressivity: pecking and distress calls*

231 The aggressive behaviour of individuals was quantified by measuring the pecks and distress  
232 calls by handled individuals in standardized trials. These trials consisted of (i) approaching a  
233 finger 1–2 cm from the beak of a bird ten times while holding its legs, and (ii) touching the  
234 bird's beak ten times with a finger (see Markó et al., 2013 for an example). During this test,  
235 we recorded the number of pecks to the hand and the number of distress calls uttered  
236 (Fucikova et al., 2009; Laiolo et al., 2009). **We expected individuals to be more aggressive in  
237 organic farming. More aggressive individuals are expected to have a better protection from a  
238 predator and thus a higher survival rate.**

239

### 240 2.3.4. *Handling vigour (flee attempts/attacks on hand)*

241 We also characterized individual behaviour during handling to measure morphological traits  
242 (see below), recording the number of times a bird attempted to flee and/or attack the hand of  
243 the experimenter with its bill or claws. Handling vigour was defined as the sum of flee  
244 attempts and attacks during morphological measurements. As for escape vigour, we expected

245 the number of flee attempts and attacks on hand to be higher for the birds caught in organic  
246 farming; hence these birds are more vigorous and able to escape a possible predator.

247

#### 248 *2.3.5. Tonic immobility*

249 Tonic immobility is a proxy measure of a bird's boldness toward predators (Réale et al.,  
250 2007). Individuals showing higher activity in the presence of a predator have a shorter  
251 duration of tonic immobility, an effective behaviour for reducing the probability of being  
252 **predated** because of lower movement stimuli eliciting attack (Thompson et al., 1981; Edelaar  
253 et al., 2012). To measure this, we induced tonic immobility by placing the bird on its back in  
254 one of the experimenter's hands, fully covering it with the other hand, and exerting light  
255 pressure to the breast area (this is intended to mimic immobilization by a predator). After 5  
256 seconds, the hand was slowly removed, and we measured the time until the bird righted itself  
257 and flew away. In the case where an individual did not move after 30 seconds, it was turned  
258 slightly upside down to trigger its escape flight. We expected tonic immobility to last longer  
259 for birds caught in organic farming increasing their probability of survivorship during  
260 predator attack.

261

262 **2.4. Morphological traits.** The measurements of morphological traits were carried out in  
263 standardized order just after the scoring of aggressivity behaviour and before the tonic  
264 immobility tests. For each bird, we measured left and right tarsus length twice. All  
265 measurements were made by the same person with a digital calliper (precision:  $\pm 0.1$  mm) to  
266 ensure the same handling time for all individuals. Body mass was recorded to the nearest 0.1  
267 g using an electronic balance (Scout Pro). Body condition was computed for each species  
268 separately based on body mass and mean tarsus length (right and left) using the scaled mass  
269 index (Peig and Green, 2009) defined as follows for each individual  $i$ :

270 
$$SMI_i = Mass_i \times \left( \frac{\text{Mean tarsus length of the group}}{Tarsus length_i} \right)^{b_{sma}}$$

271 where  $b_{sma}$  is the slope of the regression of log(body mass) on log(tarsus length)  
272 following the standard major axis method.

273

274 **2.5. Statistical analyses.** As a preliminary test, a first set of models was used to investigate  
275 the potential confounding effects of the time of capture (standardized according to the hour of  
276 sunrise), the temperature at the time of behaviour measurement, and the date of capture  
277 (transformed in Julian dates) on each measured behaviour. None of these parameters were  
278 found to significantly affect any of the recorded behaviours (all statistical test yielded  $P$  value  
279  $> 0.6$ ), and therefore potential confounding factors were ignored in subsequent analyses.  
280 Then, we opted for a two-steps approach to test first the occurrence (individuals displaying  
281 the behaviour, or not) and then the intensity of the different behaviours (including individuals  
282 that did not express the behaviour) depending on the agricultural type (organic *versus*  
283 conventional farming).

284

#### 285 *Occurrence of measured behaviours by captured individuals*

286 The occurrence of each behaviour according to the agricultural type was tested using  
287 Binomial Generalized Linear Models (B-GLM). These models computed the likelihood of an  
288 individual displaying (i.e., displayed = 1, not displayed = 0) flee attempts/attacks on hand,  
289 pecks, distress calls and tonic immobility (flying away before 30 second), with species ID,  
290 farming system, their two-way interaction, and body condition as explanatory factors. Hedge  
291 ID was added as a nested effect within the farming system (organic versus conventional) for  
292 all models to control for potential heterogeneity among capture sites. We chose to nest hedge  
293 identity inside the farming system since hedge identity is a lower-level factor appearing only  
294 within an upper-level factor (here, the farming system) (Schielzeth and Nakagawa, 2013).

295 This step was not performed for flee attempts from mist nets and breath rate as all individuals  
296 made at least one of them.

297

### 298 *Intensity of measured behaviours by captured individuals*

299 The intensity of each behaviour (including individuals that did not express the behaviour)  
300 according to the agricultural type was tested using Negative Binomial Generalized Linear  
301 Models (NB-GLM) for the parameters which were count variables (i.e., number of flee  
302 attempts/attacks, pecks, distress calls and breath rate). Negative binomial was preferred to  
303 Poisson as it fitted better the data, but tonic immobility and body condition (log-transformed)  
304 were tested with Gaussian GLM (G-GLM) as the data was normally distributed. The model  
305 structure was the same as for previous models except for body condition which only included  
306 the agricultural type and nested hedge effect as explanatory variable because it was computed  
307 independently for each species.

308 In all cases, the statistical significance of each effect was tested using deviance  
309 analysis based on likelihood-ratio  $\chi^2$  tests for B- and NB-GLM and *F*-ratio tests for G-  
310 GLM. The estimates assorted with their standard deviation for the body condition (the only  
311 continuous variable in the models) from each model are provided to allow a better  
312 understanding of the results. The sample size could vary from one behaviour to another (see  
313 Table 2 and Table 3 for exact sample sizes) because sometimes the measurements could not  
314 be taken on some individuals. All statistical tests were performed using R software (v 4.0.4, R  
315 Core Team, 2021).

316

### 317 **3. Results**

318 The findings showed that the proportion of individuals displaying handling vigour behaviour  
319 (flee attempts/attacks on hand), pecking and distress calls during the trials was species

320 dependent for all parameters (Table 2) (Fig. 1). For instance, more *P. major* individuals  
321 exhibited pecking and distress call behaviour than *S. communis*. The farming system had a  
322 significant influence only on the proportion of individuals displaying pecking behaviour:  
323 46.7% of individuals captured in organically farmed areas exhibited this behaviour, but only  
324 29.7% in conventionally farmed areas (Table 2), with no interaction with species identity. **The**  
325 **number of individuals exhibiting lasting tonic immobility (i.e., individuals not flying away**  
326 **from the hand alone) was not affected by any variables included in the model, though the**  
327 **effect of the type of agriculture was close to the significant (72.09% for individuals captured**  
328 **in organic versus 56.34% for individuals in conventionally farmed areas) (Table 2). A similar**  
329 **tendency was found for handling vigour behaviour (86.5% in organic farming versus 71.6% in**  
330 **conventional farming), but the proportion of individuals uttering distress calls was similar**  
331 **(27.8% in organic farming versus 28.4% in conventional farming).**

332         Regarding the intensity of behaviour, every monitored metric varied significantly with  
333 the farming system, except breath rate. In the latter, we found only a species effect and a  
334 strong influence of the localization of a hedge inside a farming system, indicating strong  
335 variation between different hedges inside one farming system (Fig. 2a, Table 3). The number  
336 of flee attempts of mist-netted individuals caught in organic hedges was significantly higher  
337 than in conventional hedges (Fig. 1a, Table 3). Similarly, the number of flee attempts/attacks  
338 on hand (handling vigour) was also significantly higher in organic than conventional hedges,  
339 but this was species dependent (e.g., *S. atricapilla* was more vigorous when held than *L.*  
340 *megarhynchos*) (Fig. 1b, Table 3). This handling vigour behaviour also depended on body  
341 condition (estimate  $\pm$  standard error =  $-0.10 \pm 0.03$ ; lower body condition led to higher  
342 number of flee attempts/attacks on hand) (Table 3). Aggressive behaviour (pecking and  
343 distress calls) was species dependent (e.g., *P. major* exhibited higher pecking and distress  
344 calls than *S. communis*) and higher for birds caught in organic compared to conventional



345 hedges (Fig. 1c, 1d, Table 3). In addition, there was strong variation between hedges within a  
346 type of farming system influencing the amount of pecking (Table 3). The farming system also  
347 seemed to influence the duration of tonic immobility: in organic hedges, tonic immobility  
348 lasted longer (Table 3, Fig. 3). Finally, the body condition of birds was similar between the  
349 two agricultural types (Table 3, Fig. 2b).

350

#### 351 **4. Discussion**

352 The main objective of this study was to analyse whether conventional and organic farming  
353 differentially affect a suite of captured bird behaviour and whether this varies with species.  
354 Our results showed that almost all tested behaviours differed statistically between birds  
355 caught in conventional and organic hedgerows in term of the intensity of **behavioural**  
356 **displays, but** not regarding the occurrence of such behaviours, for which we detected only a  
357 difference in the number of flee attempts/attacks on hand. This suggests that the studied  
358 behaviours were reduced in intensity, but still present, a pattern suggestive of delayed  
359 sublethal effects. Regarding the intensity of the behaviours, the number of flee attempts,  
360 handling vigour, pecking and distress calls were higher in organic than in conventional  
361 hedges. Moreover, tonic immobility lasted longer for birds caught in organic hedges. In  
362 contrast, there was no difference in breath rate or body condition between birds in the two  
363 types of farming system. These results were almost independent of the species considered (no  
364 significant interaction between agricultural type and species): all six species investigated  
365 exhibited decreased vigour when caught in conventional farming environments, indicating a  
366 strong effect of conventional farming on their behaviour whatever the ecology of the species.

367         Such a decrease in vigour may have at least two different origins. In a conventional  
368 landscape with high pesticide use, the amount of food available for birds is expected to  
369 decrease, while in organic landscapes, insect diversity and density increase (Tuck et al.,

2014). However, we found no difference in body condition, nor in breath rate, a measure of acute physiological stress. The absence of difference in breath rate is not surprising since captured birds were certainly under high stress levels during handling, despite we took care to minimise this stress with our protocol. Though breath rate can differ among personality types (Carere and van Oers, 2004), it might be a conservative trait in an acute stressful situation, and therefore, not useful as a trait to monitor the effects of environmental contaminations. Regarding the absence of difference in body condition, one explanation may be that the extensive use of pesticides in conventional agriculture has a direct effect on the physiology and behaviour of birds without altering their body condition. Indeed, several families of pesticides – especially carbamates and organophosphates – inhibit acetylcholinesterase (AChE), which is a key enzyme in the nervous system. Such pesticides have been shown to alter the behaviour of non-target species (Grue et al., 1982; Grue and Shipley, 1984; Foudoulakis et al., 2013; Borges et al., 2014; Santos et al., 2016), resulting in an overall decrease in activity and coordination (review in Grue et al., 1997; Story and Cox, 2001; Walker, 2003; Mitra et al., 2011, but see Farage-Elawar and Francis, 1988). For instance, the activity of male starlings experimentally contaminated with organophosphate was significantly reduced within 2–4 h following exposure (Grue and Shipley, 1981). In cultivated fields, birds can be contaminated by pesticides indirectly through their food or directly through contact.

**Pesticide loads may be high, even in hedges, since pesticides** can drift from the boom sprayer during application (Kjaer et al., 2014). Moreover, hedgerows can accumulate pesticides, as they intercept spray drift from the cultivated field (Lazzaro et al., 2008). Studies on the impact of spray drift on biodiversity have been largely restricted to plants and insects (Sinha et al., 1990; Davis et al., 1994; Longley and Sotherton, 1997; Longey et al., 1997): virtually no investigations have been carried out on birds. In one of the few of these, a field

395 experiment demonstrated that adult and nestling great tits were exposed to dimethoate and  
396 pirimicarb drift, suggesting a sublethal effect of pesticide drift in hedges (Cordi et al., 1997).  
397 In the future, it would be valuable to evaluate the amount of food available between the two  
398 types of landscapes, as well as dose pesticides in the captured birds, to measure their actual  
399 exposure and define the rate of accumulation of different pesticide molecules.

400         Whatever the proximate mechanisms behind these behavioural modifications observed  
401 in our study, they could lead to negative effects on the population dynamics of passerines,  
402 possibly helping to explain their decline in agricultural landscapes. For example, decreased  
403 vigour may adversely affect predator avoidance, thus increasing *in natura* mortality. For  
404 many birds, predation is the major cause of egg and chick loss and an important component in  
405 fledgling and adult mortality (Newton, 1998). Passerine predators, including wild mammals,  
406 raptors, but also domestic cats, are known to be involved in bird declines (Gibbons et al.,  
407 2007). Our results on tonic immobility may support this hypothesis, as there is increasing  
408 evidence that tonic immobility serves a functional purpose in reducing the probability of death  
409 during predator attacks and may even reduce a predator's ability to localize prey (Humphreys  
410 and Ruxton, 2008; Miyatake et al., 2009). We found that in conventional hedges, tonic  
411 immobility was shorter, suggesting that these individuals would have higher activity in the  
412 presence of a predator, hence increasing their probability of being predated or of being killed  
413 during predation (Edelaar et al., 2012). It is also possible that decreased vigour may be  
414 correlated with a decrease in the energy supplied to chicks, which is a good proxy of nestling  
415 growth rate and fledgling survival (e.g., Henderson and Hart, 1993).

416

## 417 **5. Conclusion**

418 To our knowledge, our study is the first to monitor the behaviour of birds in different  
419 agricultural systems in realistic field conditions. Our results indicate that conventional

420 farming alters several major life-history traits, which may impair individual fitness in birds.  
421 These findings suggest that passerine birds may be useful indicators of the state of the  
422 environment and could be monitored to serve as an early warning signal of specific  
423 environmental changes or to assess environmental quality in agroecosystems. However,  
424 assessing of the different behaviour we measured here may not always be feasible, as it is  
425 necessary to capture individuals (or at least tag them). Our results showed that birds in  
426 conventional farming are less vigorous and less active, therefore it is conceivable that other  
427 behaviours could show the same pattern while being easier to observe or measure. For  
428 instance, the quality of song may be altered in conventional farming systems, with birds  
429 singing less often or less intensely. Measuring singing rate does not necessitate captures.  
430 Interestingly, there is already some evidence that exposure to some pesticides impede singing  
431 ability, mating and breeding (Hart 1993). Therefore, one future prospect would be to correlate  
432 singing behavior to pesticide exposure by comparing organic and conventional landscapes.  
433 Birds have long been valued for their capacity to be used as environmental indicators: for  
434 example, through mass mortality, modifications in reproductive success and changes in the  
435 number or distribution of species communities (Becker, 2003). Thus, it seems urgent to  
436 develop studies assessing life-history traits of farmland birds in modern farming systems. In  
437 the near future, we need to correlate observed decrease in intensity of the behaviours we  
438 measured to molecules applied by farmers in conventional fields. In addition, assessing the  
439 pesticide residues in the blood of captured birds and correlating the prevalence and intensity  
440 of residues to their health would provide causality cues in explaining farmland bird decline as  
441 a result of pesticide exposure by shedding light on the potential physiological pathways  
442 leading to weakened behavioural response.  
443

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453

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455

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458

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463

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702 **Figure legends**

703 **Fig. 1:** (a) The number of flee attempts (escape vigour) of caught individual birds while still  
704 in the mist net, (b) the number of flee attempts/attacks while in the observer's hand (handling  
705 vigour) and (c) the number of pecks and (d) distress calls of handled individuals during  
706 standardized trials. Data is presented for each of the 6 species and then for all species together  
707 for organic hedges (in green, O) and in conventional hedges (in red, C). Numbers in brackets  
708 represent the number of individuals sampled. Bold line is the median; box: middle two  
709 quartiles; plain lines: 1.5 x interquartile range; open circle: extreme value.

710

711 **Fig. 2:** (a) Breath rate and (b) body condition for each of the 6 species of birds and for all  
712 birds together caught in organic hedges (in green, O) and in conventional hedges (in red, C).  
713 The numbers in brackets represent the number of adults tested. Bold line is the median; box:  
714 middle two quartiles; plain lines: 1.5 x interquartile range; open circle: extreme value.

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716 **Fig. 3:** Tonic immobility for the 6 species of birds and for all birds together caught in organic  
717 hedges (in green, O) and in conventional hedges (in red, C). The numbers in brackets  
718 represent the number of adults tested. Bold line is the median; box: middle two quartiles;  
719 plain lines: 1.5 x interquartile range; open circle: extreme value. **The size of the boxes reflects**  
720 **the variability of the behavioral response. An important proportion of birds in conventional**  
721 **agriculture flew away before the 30s while most of birds stayed in the hand up to 30s in**  
722 **organic agriculture.**

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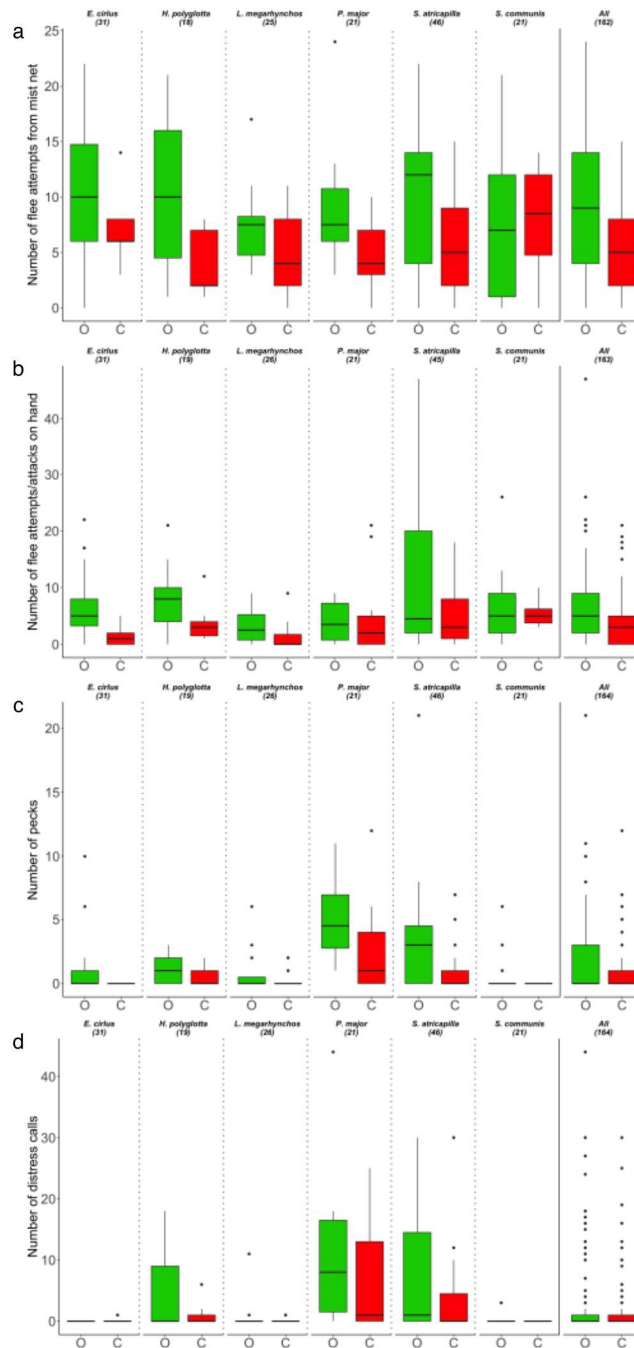


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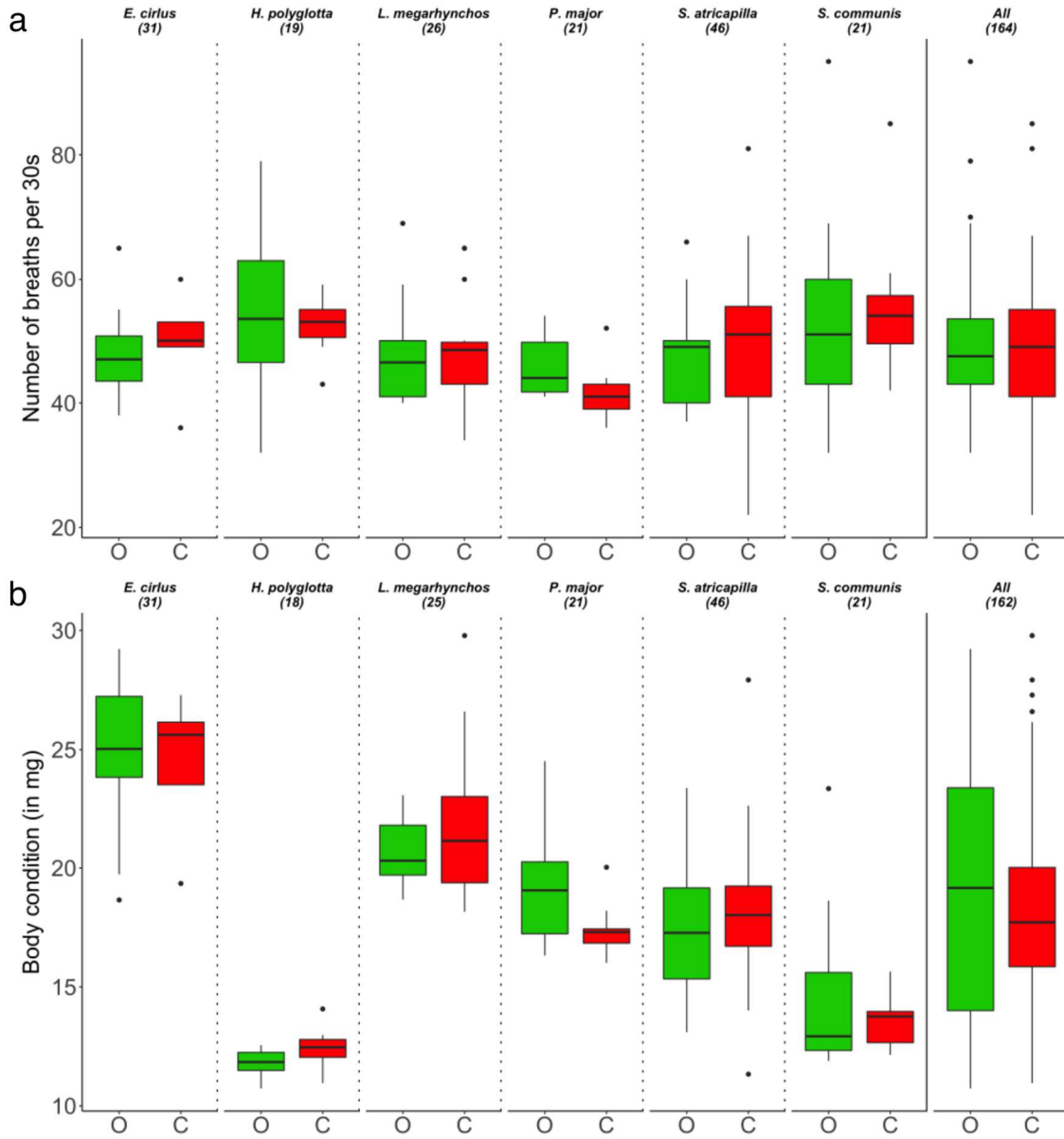
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Figure 2

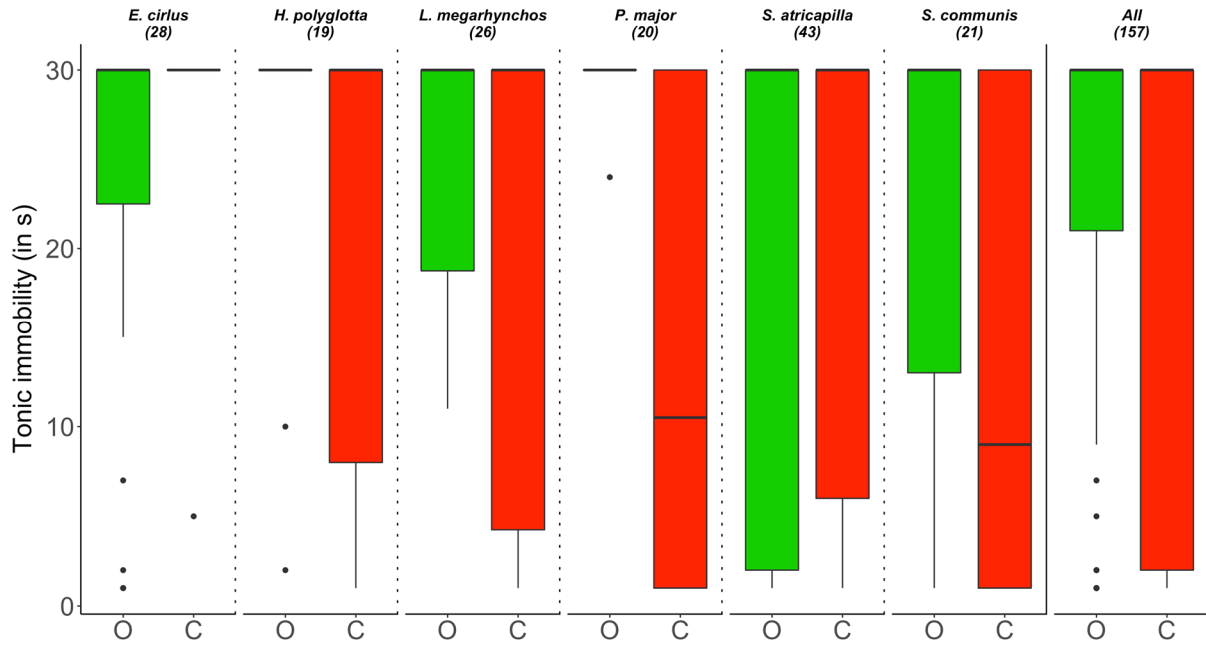
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Figure 3

Moreau et al.

762 **Table 1.** Structural characteristics of 20 hedgerows in two types of agricultural land (organic and conventional). Characteristics assessed are (i) total length, wooded  
763 length, shrubby length and length of gaps (m) and (ii) height, top width, bottom width and density (mean  $\pm$  s.e.m.), measured as the number of contacts between rod  
764 and branches with measurements made at ten different locations randomly chosen along the hedgerow. We also estimated (i) the percentage of organic farming, (ii)  
765 the percentage of wooded area and (iii) the dominant type of cultivation in a 250-m radius buffer around the hedgerow. None of these parameters measured on the 20  
766 hedges differed significantly between the two types of agricultural systems according to the Kruskal-Wallis test<sup>1</sup> or the linear model taking into account the identity  
767 of the hedge as a random factor,<sup>2</sup> except the % of organic farming within the 250-m radius buffer.  
768

Agriculture type	Hedge ID	Total Length (m)	Wooded length (m)	Shrubby length (m)	Length of gaps (m)	Height (m)	Top width (m)	Bottom width (m)	Density	% organic	% wood	Crop
<i>Organic</i>	3	411	185	411	0	3.84 $\pm$ 0.46	7.48 $\pm$ 0.97	3.81 $\pm$ 0.14	4.00 $\pm$ 0.00	98.41	0	Wheat, Triticale
	4	374	332	286	3	8.03 $\pm$ 0.84	7.04 $\pm$ 0.40	2.45 $\pm$ 0.14	1.40 $\pm$ 0.16	94.46	0	Wheat, Faba bean
	6	468	462	468	0	8.44 $\pm$ 0.45	5.83 $\pm$ 0.29	2.71 $\pm$ 0.20	2.1 $\pm$ 0.31	73.59	0	Wheat, Faba bean
	9	557	477	546	2	7.22 $\pm$ 0.82	5.60 $\pm$ 0.54	2.98 $\pm$ 0.21	1.90 $\pm$ 0.38	74.65	0	Wheat, Corn
	11	178	116	173	2	9.91 $\pm$ 1.06	6.35 $\pm$ 0.73	4.03 $\pm$ 0.77	1.70 $\pm$ 0.26	85.18	0	Wheat, Faba bean
	13	493	493	493	0	11.46 $\pm$	4.73 $\pm$ 0.52	2.55 $\pm$ 0.28	2.60 $\pm$ 0.16	96.29	6.3	Rapeseed
	14	486	52	467	0	6.67 $\pm$ 0.83	6.47 $\pm$ 0.55	2.99 $\pm$ 0.24	3.10 $\pm$ 0.23	93.13	0	Barley
	15	391	251	391	0	10.56 $\pm$	6.81 $\pm$ 0.52	3.44 $\pm$ 0.29	3.10 $\pm$ 0.18	72.94	0	Sunflower
	31	509	438	312	20	13.13 $\pm$	7.84 $\pm$ 0.80	1.88 $\pm$ 0.10	1.60 $\pm$ 0.31	73.74	0	Alfalfa
	35	190	158	106	18	12.77 $\pm$	4.19 $\pm$ 0.57	1.37 $\pm$ 0.03	1.60 $\pm$ 0.22	83.40	0	Wheat
<i>Conventional</i>	16	215	192	215	0	11.74 $\pm$	5.96 $\pm$ 0.56	2.70 $\pm$ 0.32	2.00 $\pm$ 0.30	3.51	0	Wheat
	21	527	215	520	1	10.07 $\pm$	10.69 $\pm$	2.41 $\pm$ 0.09	2.70 $\pm$ 0.34	0	0	Wheat
	22	371	352	274	25	19.23 $\pm$	4.62 $\pm$ 0.31	4.69 $\pm$ 0.62	1.70 $\pm$ 0.47	5.67	0	Faba bean, Wheat
	29	571	325	547	3	7.28 $\pm$ 1.25	6.71 $\pm$ 0.41	1.58 $\pm$ 0.08	2.10 $\pm$ 0.31	0	0	Wheat, Corn
	33	188	81	185	1	7.47 $\pm$ 1.06	3.64 $\pm$ 0.42	2.75 $\pm$ 0.38	2.10 $\pm$ 0.31	0	0	Wheat, Corn
	34	245	211	242	1	10.52 $\pm$	5.77 $\pm$ 0.65	2.89 $\pm$ 0.42	2.30 $\pm$ 0.30	0	0	Wheat, prairie
	37	217	161	205	1	11.54 $\pm$	7.20 $\pm$ 0.61	4.17 $\pm$ 0.70	2.20 $\pm$ 0.30	0	0	Wheat, Faba bean
	38	234	109	231	1	6.83 $\pm$ 0.80	7.77 $\pm$ 0.54	1.41 $\pm$ 0.07	1.70 $\pm$ 0.30	3.80	0	Barley, Wheat
40	535	449	435	9	11.40 $\pm$	7.57 $\pm$ 0.77	3.22 $\pm$ 0.89	1.70 $\pm$ 0.33	0	0	Rapeseed	
41	590	147	590	1	4.01 $\pm$ 0.60	5.26 $\pm$ 0.51	2.98 $\pm$ 0.23	3.70 $\pm$ 0.15	0	0	Wheat	
$\chi^2_{1=}$		-0.04 <sup>1</sup>	-0.94 <sup>1</sup>	-0.19 <sup>1</sup>	0.58 <sup>1</sup>	-0.54 <sup>2</sup>	-0.39 <sup>2</sup>	-0.14 <sup>2</sup>	0.27 <sup>2</sup>	-3.82 <sup>1</sup>	-0.90 <sup>1</sup>	
$P =$		0.97	0.34	0.82	0.56	0.60	0.70	0.89	0.79	0.0001	0.37	

769 **Table 2.** Occurrence of the behaviours according to the agricultural type, species identity,  
770 their interaction, body condition and nested effect of hedges within the agricultural type. Tests  
771 were performed using Binomial Generalized Linear Models (B-GLM) to compare the  
772 individuals who performed or not the behaviours. Significant effects are in bold. The  
773 estimates and standard errors for body condition are also provided for each model. **The effects**  
774 **of the categorical variables agricultural type and species are explicated in the text of the**  
775 **results.** The sample size for each behaviour appeared below the behavior.

Measured parameters		$X^2_1$	<i>df</i>	<i>P</i>
Flee attempts/ attacks on hand <sup>a</sup> N = 163	Agricultural type	2.66	1	0.10
	<b>Species</b>	<b>14.98</b>	<b>5</b>	<b>&lt; 0.05</b>
	Body condition (-0.07 ± 0.09)	0.69	1	0.41
	Agricultural type x species	4.62	5	0.46
	Agricultural type [site]	19.15	18	0.38
Pecks N = 164	<b>Agricultural type</b>	<b>11.48</b>	<b>1</b>	<b>&lt; 0.001</b>
	<b>Species</b>	<b>28.55</b>	<b>5</b>	<b>&lt; 0.0001</b>
	Body condition (-0.01 ± 0.08)	0.02	1	0.90
	Agricultural type x species	8.54	5	0.13
	Agricultural type [site]	22.76	18	0.20
Distress calls N = 164	Agricultural type	2.83	1	0.09
	<b>Species</b>	<b>36.54</b>	<b>5</b>	<b>&lt; 0.0001</b>
	Body condition (-0.03 ± 0.09)	0.14	1	0.71
	Agricultural type x species	7.83	5	0.17
	Agricultural type [site]	11.92	18	0.85
Tonic immobility N = 157	Agricultural type	3.18	1	0.07
	Species	3.49	5	0.62
	Body condition (-0.03 ± 0.08)	0.18	1	0.67
	Agricultural type x species	3.04	5	0.69
	Agricultural type [site]	25.97	18	0.10

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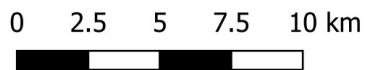
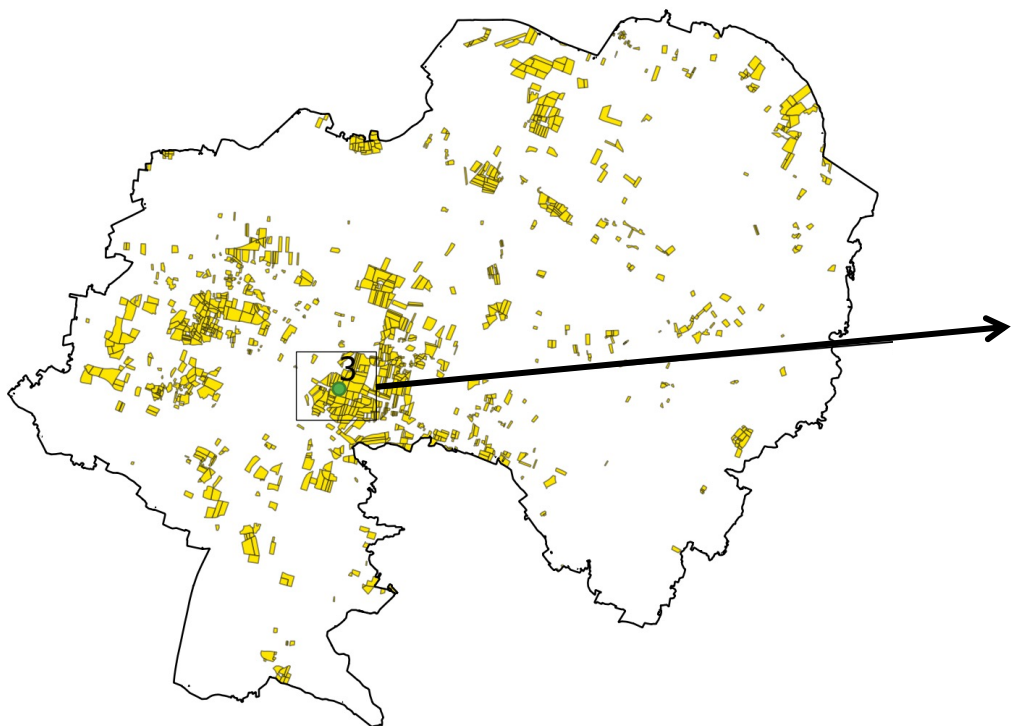
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**Table 3.** Intensity of the behaviours and body condition differences according to the agricultural type, species identity, their interaction, body condition and nested effect of hedges within the agricultural type. Tests were performed using <sup>a</sup>Negative-Binomial Generalized Linear Models (NB-GLM) or <sup>b</sup>Gaussian Generalized Linear Models (G-GLM) to compare the behavioural response of the individuals (i.e., intensity) and their body condition. Significant effects are in bold. The estimates and standard errors for body condition are also provided for each model (except the one testing for differences in body condition). **The effects of the categorical variables agricultural type and species are shown in figures.** The sample size for each behaviour appeared below the behavior.

Measured parameters		$X^2_1$	<i>df</i>	<i>P</i>
Number of flees from mist net <sup>a</sup> N = 162	<b>Agricultural type</b>	<b>15.67</b>	<b>1</b>	<b>&lt; 0.0001</b>
	Species	2.14	5	0.83
	Body condition (-0.01 ± 0.02)	0.26	1	0.61
	Agricultural type x species	5.14	5	0.40
	Agricultural type [site]	12.73	18	0.81
Number of flee attempts/ attacks on hand <sup>a</sup> N = 163	<b>Agricultural type</b>	<b>14.43</b>	<b>1</b>	<b>&lt; 0.001</b>
	<b>Species</b>	<b>20.23</b>	<b>5</b>	<b>&lt; 0.01</b>
	<b>Body condition</b> (-0.10 ± 0.03)	<b>9.31</b>	<b>1</b>	<b>&lt; 0.01</b>
	Agricultural type x species	5.35	5	0.37
	Agricultural type [site]	24.45	18	0.14
Number of pecks <sup>a</sup> N = 164	<b>Agricultural type</b>	<b>23.87</b>	<b>1</b>	<b>&lt; 0.0001</b>
	<b>Species</b>	<b>39.28</b>	<b>5</b>	<b>&lt; 0.0001</b>
	Body condition (-0.005 ± 0.05)	0.01	1	0.91
	Agricultural type x species	5.38	5	0.37
	<b>Agricultural type [site]</b>	<b>34.37</b>	<b>18</b>	<b>&lt; 0.05</b>
Number of distress calls <sup>a</sup> N = 164	<b>Agricultural type</b>	<b>6.43</b>	<b>1</b>	<b>&lt; 0.05</b>
	<b>Species</b>	<b>65.61</b>	<b>5</b>	<b>&lt; 0.0001</b>
	Body condition (-0.07 ± 0.09)	0.48	1	0.49
	Agricultural type x species	6.83	5	0.23
	Agricultural type [site]	15.31	18	0.64
Breath rate <sup>a</sup> N = 164	Agricultural type	0.14	1	0.71
	<b>Species</b>	<b>29.18</b>	<b>5</b>	<b>&lt; 0.0001</b>
	Body condition (0.008 ± 0.005)	2.55	1	0.11
	Agricultural type x species	2.32	5	0.80
	<b>Agricultural type [site]</b>	<b>51.38</b>	<b>18</b>	<b>&lt; 0.0001</b>
Duration of tonic immobility <sup>b</sup> N = 157	<b>Agricultural type</b>	<b>5.37</b>	<b>1</b>	<b>&lt; 0.05</b>
	Species	2.38	5	0.79
	Body condition (0.20 ± 0.42)	0.22	1	0.64
	Agricultural type x species	3.07	5	0.69
	Agricultural type [site]	19.75	18	0.35
Body condition (log-transformed) <sup>b</sup> N = 164	Agricultural type	0.69	1	0.40
	Agricultural type [site]	23.31	18	0.18

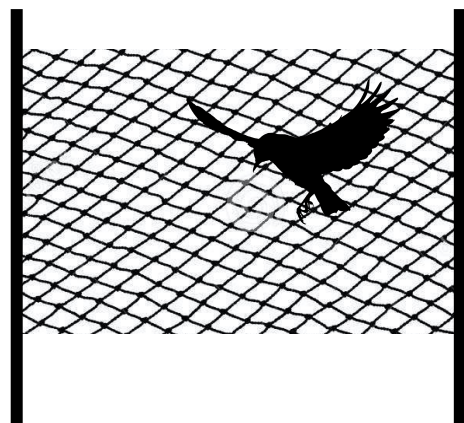
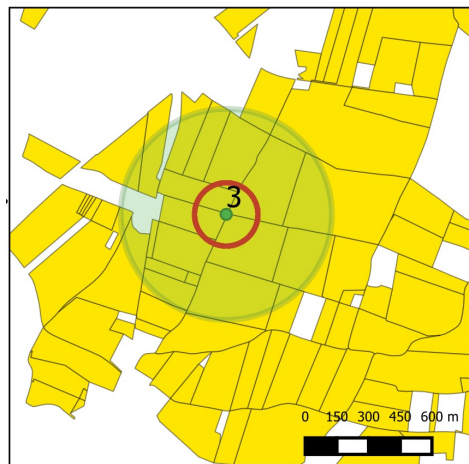
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Long-Term Social-Ecological Research (LTSER) site in central western France



- Organically farmed fields (O)
- Conventionally farmed fields (C)

10 hedges in O  
vs.  
10 hedges in C



Bird catching  
6 species

Handling  
behaviour

