



HAL
open science

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

Jérôme Moreau, Karine Monceau, Gladys Gonnet, Marie Pfister, Vincent Bretagnolle

► **To cite this version:**

Jérôme Moreau, Karine Monceau, Gladys Gonnet, Marie Pfister, Vincent Bretagnolle. Organic farming positively affects the vitality of passerine birds in agricultural landscapes.. Agriculture, Ecosystems & Environment, 2022, 336, pp.108034. 10.1016/j.agee.2022.108034 . hal-03693423

HAL Id: hal-03693423

<https://hal.science/hal-03693423v1>

Submitted on 22 Jul 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

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 (Clotflelter 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 km² 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: ± 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 χ^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 ± 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

444 **Acknowledgements:** We would like to thank all the farmers who allowed us free access to
445 their fields, as well as all those who contributed to the fieldwork.

446

447 **Funding:** This work was supported by the University of La Rochelle, the French National
448 Centre of Scientific Research (CNRS), and the French National Research Institute for
449 Agriculture, Food and the Environment (INRAE). This study was partly funded by the
450 projects BIRDPEST funded by RECOTOX 2019, ACI funded by the University of La
451 Rochelle, AgriBioBird funded by OSU Theta ISITE-BFC, ANR JCJC PestiStress (#19-CE34-
452 0003-01), and the BioBird project funded by the regional government of Nouvelle-Aquitaine.

453

454 **Competing interests:** The authors declare no competing interests.

455

456 **Data accessibility:** Once the paper has been accepted, the data will be deposited in the Dryad
457 repository.

458

459 **Research ethics:** All experiments complied with French regulations on animal
460 experimentation. We are grateful to the Nouvelle-Aquitaine Regional Agency of the
461 Environment, Development and Housing for the official capture authorizations
462 (DREAL/2019D/2323).

463

464 **References**

465 Albayrak, T., Mor, F., 2011. Comparative tissue distribution of heavy metals in house
466 sparrow (*Passer domesticus*, Aves) in polluted and reference sites in Turkey. Bull.
467 Environ. Contam. Toxicol. 87, 457-462.

468 Arnold, G.W., 1983. The influence of ditch and hedgerow structure, length of hedgerows, and
469 area of woodland and garden on bird numbers on farmland. *J. Appl. Ecol.* 20(3), 731-750.

470 Assandri, G., Morganti, M., Bogliani, G., Pulido, F., 2017. The value of abandoned olive
471 groves for blackcaps (*Sylvia atricapilla*) in a Mediterranean agroecosystem: a year-round
472 telemetry study. *Eur. J. Wildl. Res.* 63, 26.

473 Baeta, R., Belisle, M., Garant, D., 2012. Agricultural intensification exacerbates female-
474 biased primary brood sex-ratio in tree swallows. *Landscape Ecol.* 27, 1395-1405.

475 Batary, P., Matthiesen, T., Tschardtke, T., 2010. Landscape-moderated importance of hedges
476 in conserving farmland bird diversity of organic vs. conventional croplands and
477 grasslands. *Biol. Conserv.* 143, 2020-2027.

478 Becker, P.H., 2003. Chapter 19 Biomonitoring with birds. *Trace Metals and other*
479 *Contaminants in the Environment*, 6, 677-736.

480 *Birds of the World*, 2022. Edited by S. M. Billerman, B. K. Keeney, P. G. Rodewald, and T.
481 S. Schulenberg. Cornell Laboratory of Ornithology, Ithaca, NY,
482 USA. <https://birdsoftheworld.org/bow/home>

483 Borges, S.L., Vyas, N.B., Christman, M.C., 2014. The influence of study species selection on
484 estimates of pesticide exposure in free-ranging birds. *Environ. Manag.* 53, 416-428.

485 Bretagnolle, V., Berthet, E., Gross, N., Gauffre, B., Plumejeaud, C., Houte, S., Badenhauer,
486 I., Monceau, K., Allier, F., Monestiez, P., Gaba, S., 2018. Towards sustainable and
487 multifunctional agriculture in farmland landscapes: Lessons from the integrative
488 approach of a French LTSER platform. *Sci. Total Environ.* 627, 822-834.

489 Carere, C., van Oers, K., 2004. Shy and bold great tits (*Parus major*): body temperature and
490 breath rate in response to handling stress. *Physiol. Behav.* 82, 905-912.

491 Chamberlain, D.E., Joys, A., Johnson, P.J., Norton, L., Feber, R.E., Fuller R.J., 2010. Does
492 organic farming benefit farmland birds in winter? *Biol. Lett.* 6, 82-84.

493 Chamberlain, D.E., Fuller, R.J., Bunce, R.G.H., Duckworth, J.C., Shrubbs, M., 2000. Changes
494 in the abundance of farmland birds in relation to the timing of agricultural intensification
495 in England and Wales. *J. Appl. Ecol.* 37, 771-788. [http://doi.org/10.1046/j.1365-](http://doi.org/10.1046/j.1365-2664.2000.00548.x)
496 2664.2000.00548.x

497 Chiron, F., Chargé, R., Julliard, R., Jiguet, F., Muratet, A., 2014. Pesticide doses, landscape
498 structure and their relative effects on farmland birds. *Agric. Ecosyst. Environ.* 185, 153-
499 160.

500 Clotfleter, E.D., Bell, A.M., Levering K.R., 2004. The role of animal behaviour in the
501 study of endocrine-disrupting chemicals. *Anim. Behav.* 68, 665-676.

502 Cordi, B., Fossi, C., Depledge, M., 1997. Temporal biomarker responses in wild passerine
503 birds exposed to pesticide spray drift. *Environ. Toxicol. Chem.* 16(10), 2118-2124.

504 Davis, B.N.K., Brown, M.J., Frost, A.J., Yates, T.J., Plant R.A., 1994. The effects of hedges
505 on spray deposition and on the biological impact of pesticide spray drift. *Ecotoxicol.*
506 *Environ. Saf.* 27, 281-293.

507 Dell’Omo, G., 2002. *Behavioral Ecotoxicology*. Wiley, New York.

508 Edelaar, P., Serrano, D., Carrete, M., Blas, J., Potti, J., Tella J.L., 2012. Tonic immobility is a
509 measure of boldness toward predators: an application of Bayesian structural equation
510 modelling. *Behav. Ecol.* 23, 619-626.

511 Farage-Elawar, M., Francis, B.M., 1988. Effects of multiple dosing of fenthion, fenitrothion,
512 and desbromoleptophos in young chicks. *J. Toxicol. Environ. Health* 23, 217-228.

513 Fluetsch, K.M., Sparling, D.W., 1991. Avian nesting success and diversity in conventionally
514 and organically managed apple orchards. *Environ. Toxicol. Chem.* 13(10), 1651-1659.

515 Foudoulakis, M., Balaskas, C., Csato, A., Szentes, C., Arapis, G., 2013. Japanese quail acute
516 exposure to methamidophos: Experimental design, lethal, sub-lethal effects and

517 cholinesterase biochemical and histochemical expression. *Sci. Total Environ.* 450–451,
518 334-347.

519 Fucikova, E., Drent, P. J., Smits, N., van Oers, K., 2009. Handling stress as a measurement of
520 personality in great tit nestlings (*Parus major*). *Ethology* 115, 366-374.

521 Geiger, F., Bengtsson, J., Berendse, F., Weisser, W.W., Emmerson, M., Morales, M.B.,
522 Ceryngier, P., Liira, J., Tschardtke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T.,
523 Bretagnolle, V., Plantegenest, M., Clement, L.W., Dennis, C., Palmer, C., Onate, J.J.,
524 Guerrero, I., Hawro, V., Aavik, T., Thies, C., Flohre, A., Hänke, S., Fischer, C.,
525 Goedhart, P.W., Inchausti, P., 2010. Persistent negative effects of pesticides on
526 biodiversity and biological control potential on European farmland. *Basic Appl. Ecol.* 11,
527 97-105.

528 Gibbons, D.W., Amar, A., Anderson, G.Q.A., Bolton, M., Bradbury, R.B., Eaton, M.A.,
529 Evans, A.D., Grant, M.C., Gregory, R.D., Hilton, G.M., Hirons, G.J.M., Hughes, J.,
530 Johnstone, I., Newbery, P., Peach, W.J., Ratcliffe, N., Smith, K.W., Summers, R.W.,
531 Walton, P., Wilson, J.D., 2007. The predation of wild birds in the UK: a review of its
532 conservation impact and management. RSPB Research Report no 23. RSPB, Sandy.

533 Gibson, R.H., Pearce, S., Morris, R.J., Symondson, W.O.C., Memmott, J., 2007. Plant
534 diversity and land use under organic and conventional agriculture: A whole-farm
535 approach. *J. Appl. Ecol.* 44(4), 792-803.

536 Gonthier, D.J., Ennis, K.K., Farinas, S., Hsieh, H.Y., Iverson, A.L., Batary, P., Rudolphi J.,
537 Tschardtke, T., Cardinale, B.J., Perfecto, I., 2014. Biodiversity conservation in
538 agriculture requires a multi-scale approach. *Proc. R. Soc. B Biol. Sci.* 281, 20141358.

539 Green, R.E., Osborne, P.E., Sears E.J., 1994. The distribution of passerine birds in hedgerows
540 during the breeding season in relation to characteristics of the hedgerow and adjacent
541 farmland. *J. Appl. Ecol.* 31, 677-692.

542 Gregory, R.D., Skorpilovac, J., Vorisek, P., Butler, S., 2019. An analysis of trends,
543 uncertainty and species selection shows contrasting T trends of widespread forest and
544 farmland birds in Europe. *Ecol Indic.* 103, 676-687.

545 Grue, C.E., Shipley, B.K., 1981. Interpreting population estimates of birds following pesticide
546 applications – behavior of male starlings exposed to an organophosphate pesticide. *Stud.*
547 *Avian Biol.* 6, 292-296.

548 Grue, C.E., Gibert, P.L., Seeley, M.E., 1997. Neurophysiological and behavioral changes in
549 non-target wildlife exposed to organophosphate and carbamate pesticides:
550 thermoregulation, food consumption, and reproduction. *Amer. Zool.* 37, 369-388.

551 Grue, C.E., Shipley, B.K., 1984. Sensitivity of nestling and adult starlings to dicrotophos, and
552 organophosphate pesticide. *Environ. Res.* 35, 454-465.

553 Grue, C.E., Powell, G.V.N., McChesney, M.J., 1982. Care of nestlings by wild female
554 starlings exposed to an organophosphate pesticide. *J. Appl. Ecol.* 19, 327-335.

555 Halupka, K., Borowiec, M., Karczewska, A., Kunka, A., Pietrowiak, J., 2002. Habitat
556 requirements of Whitethroats *Sylvia communis* breeding in an alluvial plain. *Bird Stud.*
557 49, 297-299.

558 Hart, A. D. M. 1993. Relationship between behavior and the inhibition of acetylcholinesterase
559 in birds exposed to organophosphorus pesticides. *Environ. Toxicol. Chem.* 12, 321-336.

560 Hellou, J., Cheeseman, K., Desnoyers, E., Johnston, D., Jouvenelle, M.L., Leonard, J.,
561 Robertson, S., Walker, P., 2008. A non-lethal chemically based approach to investigate
562 the quality of harbour sediments. *Sci. Total. Environ.* 389, 178-187.

563 Hellou, J. (2011). Behavioural ecotoxicology, an “early warning” signal to assess
564 environmental quality. *Environ. Sci. Pollut. Res.* 18, 1-11.

565 Henderson, I.G., Hart, P.J.B., 1993. Provisioning, parental investment and reproductive
566 success in jackdaws *Corvus monedula*. *Ornis Scand.* 24, 142-148.

567 Hole, D.G., Whittingham, M.J., Bradbury, R.B., Anderson, G.Q.A., Lee, P.L.M., Wilson,
568 J.D., Krebs, J.R., 2002. Widespread local house-sparrow extinctions – agricultural
569 intensification is blamed for the plummeting populations of these birds. *Nature* 418, 931-
570 932.

571 Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P.V., Evans, A., 2005. Does
572 organic farming benefit biodiversity? *Biol. Cons.* 122(1), 113-130.
573 <https://doi.org/10.1016/j.biocon.2004.07.018>.

574 Humphreys, R.K., Ruxton, G.D., 2008. A review of thanatosis (death feigning) as an anti-
575 predator behaviour. *Behav. Ecol. Sociobiol.* 72(2), 22.

576 Kjaer, C., Bruus, M., Bossi, R., Lofstrom, P., Andersen, H.V., Nuyttens, D., Larsen, S.E.,
577 2014. Pesticide drift deposition in hedgerows from multiple spray swaths. *J. Pestic. Sci.*
578 39, 14-21.

579 Laiolo, P., Banda, E., Lemus, J.A., Aguirre, J.I., Blanco, G., 2009. Behaviour and stress
580 response during capture and handling of the red-billed chough *Pyrrhocorax pyrrhocorax*
581 (Aves: Corvidae). *Biol. J. Linn. Soc.* 96, 846-855.

582 Lazzaro, L., Otto, S., Zanin, G., 2008. Role of hedgerows in intercepting spray drift:
583 Evaluation and modelling of the effects. *Agric. Ecosyst. Environ.* 123, 317-327.

584 Longey, M., Cilgi, T., Jepson, P.C., Sotherton, N.W., 1997. Measurements of pesticide spray
585 drift deposition into field boundaries and hedgerows: 1. Summer applications. *Environ.*
586 *Toxicol. Chem.* 16(2), 165-172.

587 Longey, M., Sotherton, N.W., 1997. Measurements of pesticide spray drift deposition into
588 field boundaries and hedgerows: 2. Autumn applications. *Environ. Toxicol. Chem.* 16(2),
589 173-178.

590 Lopez-Antia, A., Ortiz-Santaliestra, M.E., Mougeot, F., Mateo, R., 2015. Imidacloprid-treated
591 seed ingestion has lethal effect on adult partridges and reduces both breeding investment
592 and offspring immunity. *Environ. Res.* 136, 97-107

593 Lushchak, V.I., Matviishyn, T.M., Husak, V.V., Storey, J.M., Storey, K.B., 2018. Pesticide
594 toxicity: a mechanistic approach. *Excli Journal* 7, 1101-1136

595 MacDonald, D.W., Johnson, P.J., 1995. The relationship between bird distribution and the
596 botanical and structural characteristics of hedges. *J. Appl. Ecol.* 32, 492-505

597 Markó, G., Azcarate, M., Hegyi, G., Herceg, G., Laczi, M., Nagy, G., Senar, J.C., Torok, J.,
598 Garamszegi, L.Z., 2013. Behavioural responses to handling stress in the Great Tit:
599 within-individual consistency and the effect of age, sex and body condition. *Ornis Hung.*
600 21(1), 12-25.

601 McKenzie, A.J., Whittingham, M.J., 2009. Why are birds more abundant on organic farms? *J.*
602 *Food Agric. Environ.* 7, 807-814.

603 Millot, F., Decors, A., Mastain, O., Quintaine, T., Berny, P., Vey, D., Lasseur, R., Bro, E.,
604 2017. Field evidence of bird poisonings by imidacloprid-treated seeds: a review of
605 incidents reported by the French SAGIR network from 1995 to 2014. *Environ. Sci.*
606 *Pollut. Res.* 24, 5469-5485.

607 Mineau, P., Whiteside, M., 2013. Pesticide acute toxicity is a better correlate of U.S.
608 grassland bird declines than agricultural intensification. *PLoS ONE* 8(2): e57457.

609 Mitra, A., Chatterjee, C., Mandal, F.B., 2011. Synthetic Chemical Pesticides and Their Effects
610 on Birds. *Res. J. Environ. Toxicol.* 5, 81-96.

611 Miyatake, T., Nakayama, S., Nishi, Y., Nakajima, S., 2009. Tonically immobilized selfish
612 prey can survive by sacrificing others. *Proc. R. Soc. B.* 276, 2763-2767.

613 Mondelaers, K., Aertsens, J., Van Huylenbroeck, G., 2009. A meta-analysis of the differences
614 in environmental impacts between organic and conventional farming. *Brit. Food. J.* 111,
615 1098-1119.

616 Moreau, J., Monceau, K., Crépin, M., Derouin-Tochon, F., Mondet, C., Frainkin, M.,
617 Teixeira, M., Bretagnolle, V., 2021. Feeding partridges with organic or conventional
618 grain triggers cascading effects in life-history traits. *Environ. Poll.* 278, 116851.

619 Moskat, C., Baldi, A., Waliczky, Z., 1993. Habitat selection of breeding and migrating
620 icterine warblers *Hippolais icterina*: a multivariate study. *Ecography* 16, 137-142.

621 Naef-Daenzer, B., 1994. Radiotracking of great and blue tits: new tools to assess territoriality,
622 home-range use and resource distribution. *Ardea* 82, 335-347.

623 Naguib, M., Altenkamp, R., Griessmann, B., 2001. Nightingales in space: song and extra-
624 territorial forays of radio-tagged songbirds. *J. Ornithol.* 142, 306-312.

625 Newton, I., 1998. *Population Limitation in Birds*. Academic Press, London.

626 Odum, E.P., 1971. *Fundamentals of Ecology*, 3rd edn. Philadelphia: W.B. Saunders.

627 Peakall, D.B., 1985. Behavioral responses of birds to pesticides and other contaminants.
628 *Residue Rev.* 96, 45-77.

629 Peig, J., Green, A.J., 2009. New perspectives for estimating body condition from mass/length
630 data: the scaled mass index as an alternative method. *Oikos* 118, 1883e1891.

631 R Core Team. (2021). *R: A Language and Environment for Statistical Computing*. R
632 Foundation for Statistical Computing. Vienna, Austria.

633 Rabdeau, J., Badenhauer, I., Moreau, J., Bretagnolle, V., Monceau K., 2019. To change or
634 not to change experimenters: caveats for repeated behavioural and physiological
635 measures in Montagu's harrier. *J. Avian Biol.* 50(8), e02160.

636 Réale, D., Reader, S.M., Sol, D., McDougall, P.T. Dingemanse, N.J., 2007. Integrating animal
637 temperament within ecology and evolution. *Biol. Rev.* 82, 291-318.

638 Reganold, J.P., Watcher, J.M., 2016. Organic agriculture in the twenty-first century. *Nature*
639 *Plants* 2, 15221.

640 Robertson, G.P., Gross, K.L., Hamilton, S.K., Landis, D.A., Schmidt, T.M., Snapp, S.S.,
641 Swinton, S.M., 2014. Farming for ecosystem services: an ecological approach to
642 production agriculture. *Bioscience* 2004, 61-65.

643 Robinson, R.A., Sutherland, W.J., 2002. Post-war changes in arable farming and biodiversity
644 in Great Britain. *J. Appl. Ecol.* 3, 157-176.

645 Sandhu, H.S., Wratten, S.D., Cullen, R., 2010. Organic agriculture and ecosystem services.
646 *Environ. Sci. Policy* 13(1), 1-7. <https://doi.org/10.1016/j.envsci.2009.11.002>

647 Santos, C.S.A., Monteiro, M.S., Soares, A.M.V.M., Loureiro, S., 2016. Brain cholinesterase
648 reactivation as a marker of exposure to anticholinesterase pesticides: a case study in a
649 population of yellow-legged gull *Larus michahellis* (Naumann, 1840) along the northern
650 coast of Portugal. *Environ. Sci. Pollut. Res.* 23, 266-272.

651 Schielzeth, H., Nakagawa, S., 2013. Nested by design: model fitting and interpretation in a
652 mixed model era. *Meth. Ecol. Evol.* 4, 14–24.

653 Seufert, V., Ramankutty, N., Foley, J.A., 2012. Comparing the yields of organic and
654 conventional agriculture. *Nature* 485, 229-232.

655 Sinha, S.A., Lakhani K.H., Davis, B.N.K., 1990. Studies on the toxicity of insecticidal drift to
656 the first instar larvae of the large white butterfly *Pieris brassicae* (Lepidoptera: Pieridae).
657 *Ann. Appl. Biol.* 116, 27-41.

658 Smith, H.G., Danhardt, J., Lindstrom, A., Rundlof, M. 2010. Consequences of organic
659 farming and landscape heterogeneity for species richness and abundance of farmland
660 birds. *Oecologia* 162, 1071-1079.

661 Stanton, R.L., Morrissey, C.A., Clark, R.G., 2018. Analysis of trends and agricultural drivers
662 of farmland bird declines in North America: A review. *Agric. Ecosyst. Environ.* 254,
663 244-254.

664 Stevens, D.K., Donald, P.F., Evans, A.D., Buckingham, D.L., Evans, J., 2002. Territory
665 distribution and foraging patterns of ciril buntings (*Emberiza cirilus*) breeding in the UK.
666 *Biol. Cons.* 107, 307-313.

667 Stoate, C., Szczur, J., 2001. Whitethroat *Sylvia communis* and Yellowhammer *Emberiza*
668 *citrinella* nesting success and breeding distribution in relation to field boundary
669 vegetation. *Bird Stud.* 48, 229-235.

670 Stoate, C., Báldi, A., Beja, P., Boatman, N.D., Herzon, I., van Doorn, A., de Snoo, G.R.,
671 Rakosy, L., Ramwell, C., 2009. Ecological impacts of early 21st century agricultural
672 change in Europe - A review. *J. Environ. Manage.* 91(1), 22-46.
673 <https://doi.org/10.1016/j.jenvman.2009.07.005>

674 Story, P., Cox, M., 2001. Review of the effects of organophosphorus and carbamate
675 insecticides on vertebrates. Are there implications for locust management in Australia?
676 *Wildl. Res.* 28, 179-193.

677 Thompson, R. K. R., Foltin, R. W., Boylan, R. J., Sweet, A., Graves, C. A., Lowitz, C. E.,
678 1981. Tonic immobility in Japanese quail can reduce the probability of sustained attack
679 by cats. *Anim. Learn. Behav.* 9, 145-149.

680 Toppari, J., Larsen, J.C., Christiansen, P., Giwercman, A., Grandjean, P., Guillette Jr., L.J.,
681 Jegou, B., Jensen, T.K., Jouannet, P., Keiding, N., Leffers, H., McLachlan, J.A., Meyer,
682 O., Muller, J., Rajpert-De Meyts, E., Scheike, T., Sharpe, R., Sumpter, J., Skakkebaek,
683 N.E., 1996. Male reproductive health and environmental xenoestrogens. *Environ.*
684 *Health Perspect.* 104, 741e803.

685 Torné-Noguera, A., Pagani-Núñez, E., Senar, J.C., 2014. Great tit (*Parus major*) breath rate in
686 response to handling stress: urban and forest birds differ. *J. Ornithol.* 155, 315-318.

687 Tuck, S.L., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L.A., Bengtsson, J., 2014. Land-
688 use intensity and the effects of organic farming on biodiversity: A hierarchical meta-
689 analysis. *J. Appl. Ecol.* 51(3), 746-755. <https://doi.org/10.1111/1365-2664.12219>

690 Walker, C.H., 2003. Neurotoxic Pesticides and Behavioural Effects Upon Birds.
691 *Ecotoxicology* 12, 307-316.

692 Wiegand, C., 2019. Strategies and consequences of indigenous and invasive freshwater
693 mussels living in cyanobacterial and anthropogenic impacted waters, in: Groos, E.,
694 Garic, J. (Eds.), *Ecotoxicology New Challenges and New Approaches*. Elsevier, Oxford,
695 pp. 93-128.

696 Wintermantel, D., Odoux, J.F., Chadoeuf, J., Bretagnolle, V., 2019. Organic farming
697 positively affects honeybee colonies in a flower-poor period in agricultural landscapes. *J.*
698 *Appl. Ecol.* 56(8), 1960-1969.

699 Zhang, F., Chen, X., Vitousek, P., 2013. Chinese agriculture: an experiment for the world.
700 *Nature* 497, 33-35.

701

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.

715

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.**

723

724

725

726

727

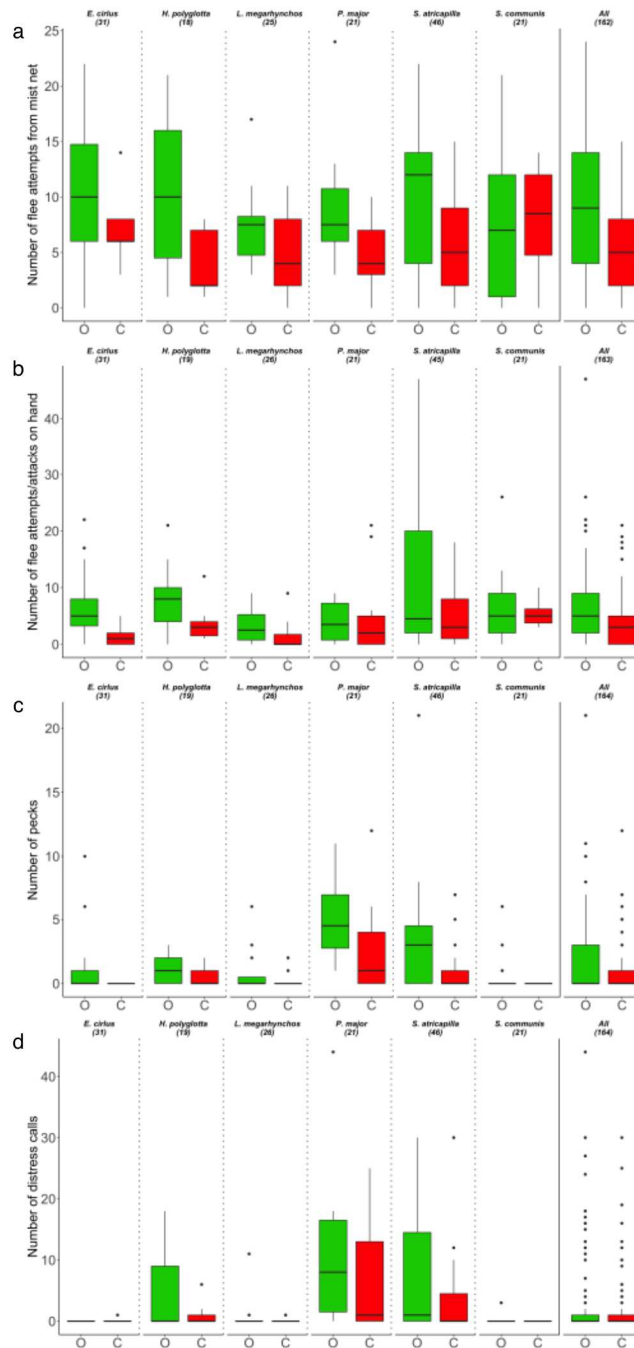
728

729

730

731

732



733

734

735

736

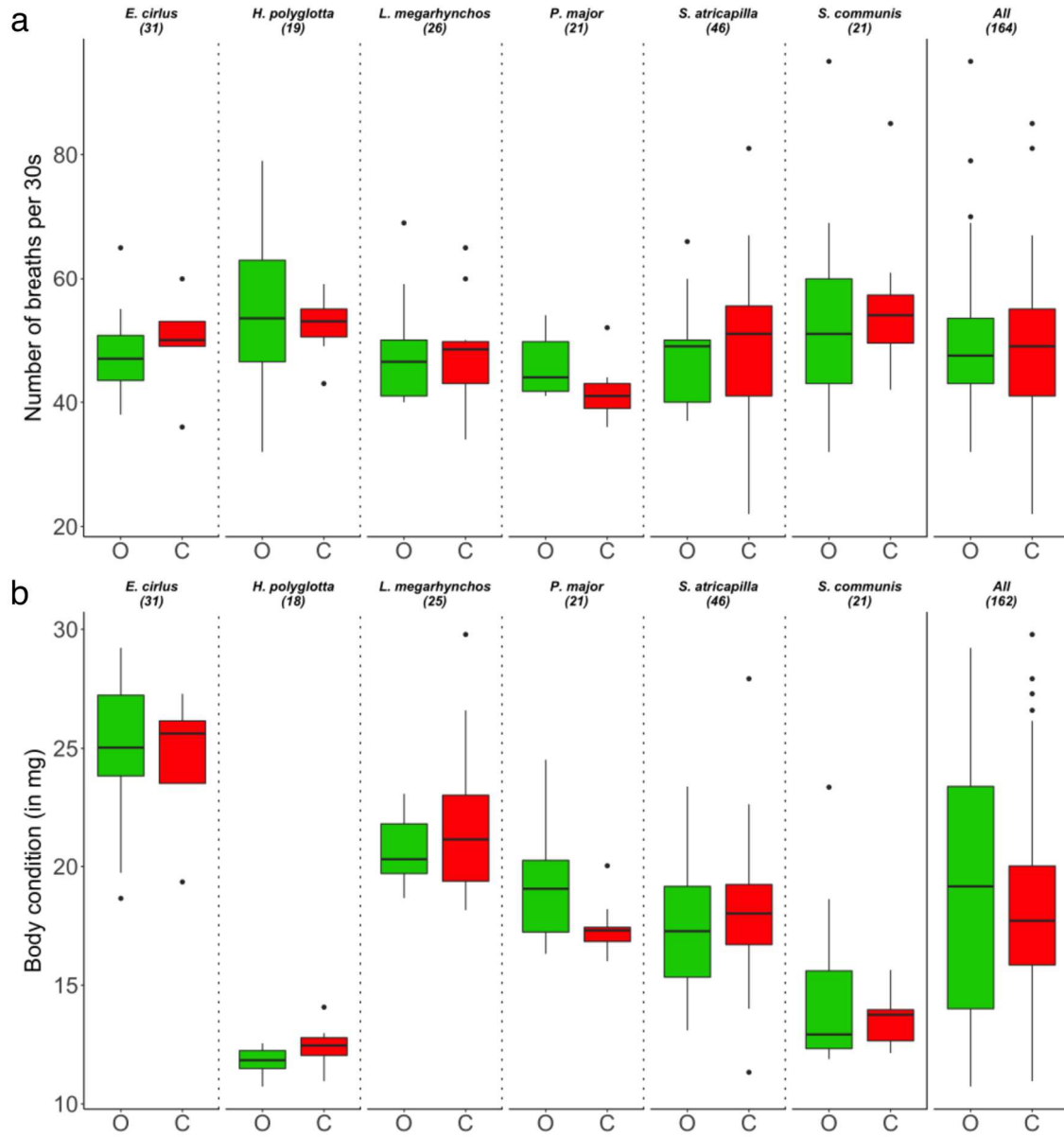
Figure 1

737

738

739

740



741

742

743

Figure 2

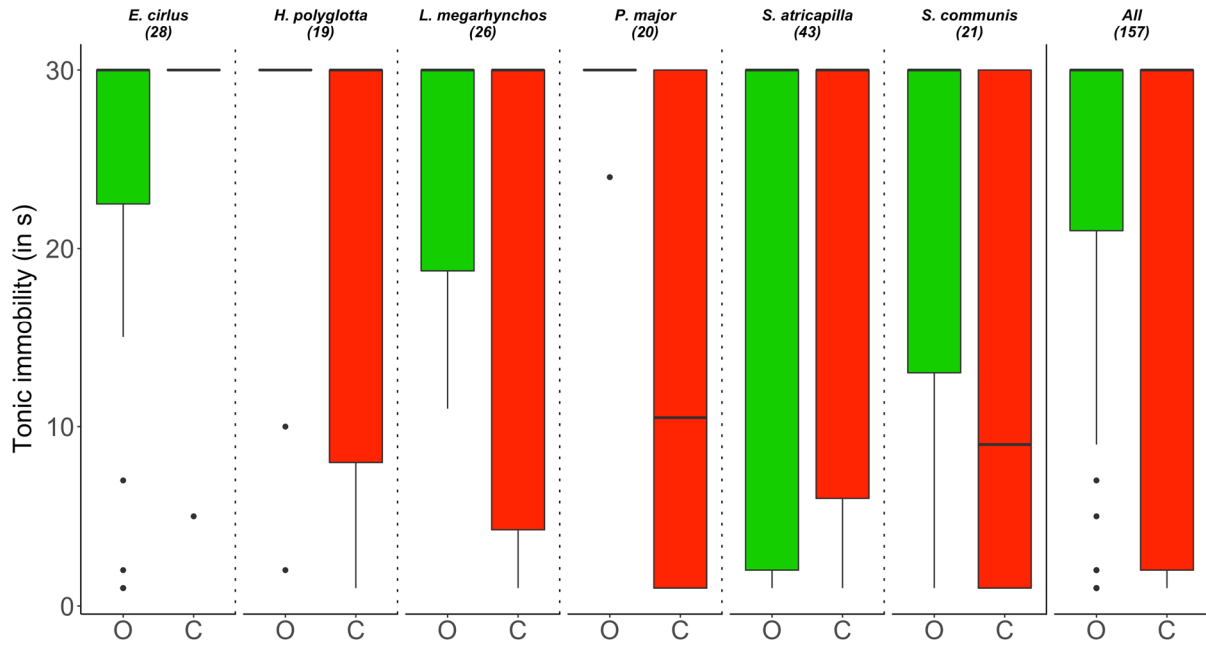
744

745

746

747

748



749

750

751

752

753

754

755

756

757

758

759

760

Figure 3

761

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 test¹ or the linear model taking into account the identity
767 of the hedge as a random factor,² 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 ¹	-0.94 ¹	-0.19 ¹	0.58 ¹	-0.54 ²	-0.39 ²	-0.14 ²	0.27 ²	-3.82 ¹	-0.90 ¹	
$P =$		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 ^a N = 163	Agricultural type	2.66	1	0.10
	Species	14.98	5	< 0.05
	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	Agricultural type	11.48	1	< 0.001
	Species	28.55	5	< 0.0001
	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
	Species	36.54	5	< 0.0001
	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

776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796

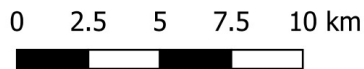
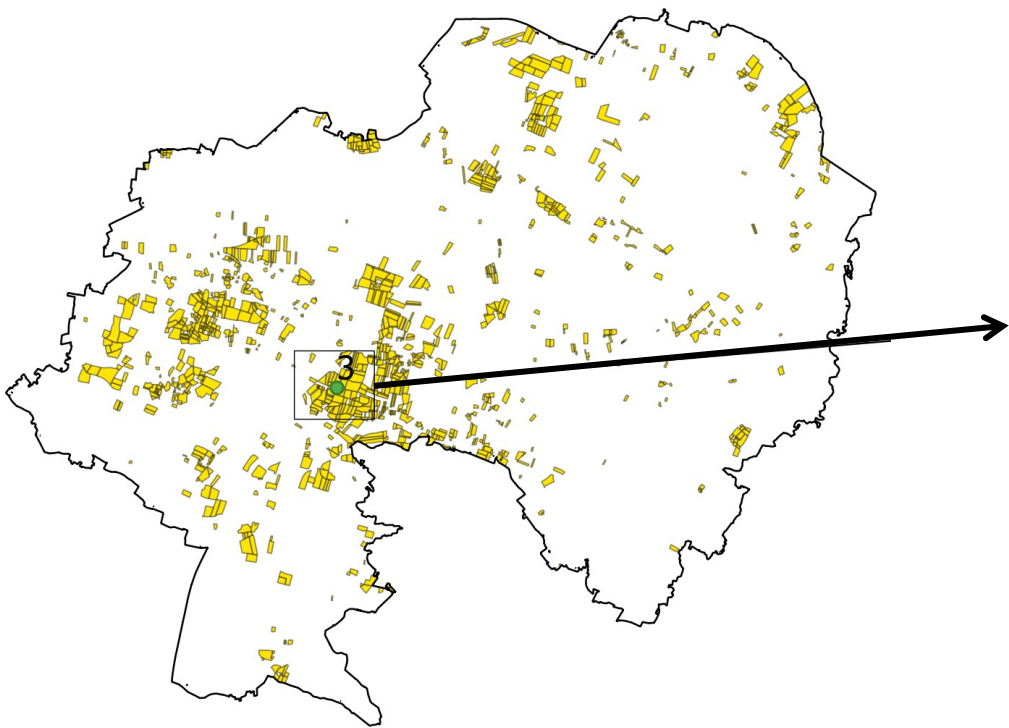
797
798
799
800
801
802
803
804
805
806
807

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 ^aNegative-Binomial Generalized Linear Models (NB-GLM) or ^bGaussian 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 ^a N = 162	Agricultural type	15.67	1	< 0.0001
	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 ^a N = 163	Agricultural type	14.43	1	< 0.001
	Species	20.23	5	< 0.01
	Body condition (-0.10 ± 0.03)	9.31	1	< 0.01
	Agricultural type x species	5.35	5	0.37
	Agricultural type [site]	24.45	18	0.14
Number of pecks ^a N = 164	Agricultural type	23.87	1	< 0.0001
	Species	39.28	5	< 0.0001
	Body condition (-0.005 ± 0.05)	0.01	1	0.91
	Agricultural type x species	5.38	5	0.37
	Agricultural type [site]	34.37	18	< 0.05
Number of distress calls ^a N = 164	Agricultural type	6.43	1	< 0.05
	Species	65.61	5	< 0.0001
	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 ^a N = 164	Agricultural type	0.14	1	0.71
	Species	29.18	5	< 0.0001
	Body condition (0.008 ± 0.005)	2.55	1	0.11
	Agricultural type x species	2.32	5	0.80
	Agricultural type [site]	51.38	18	< 0.0001
Duration of tonic immobility ^b N = 157	Agricultural type	5.37	1	< 0.05
	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) ^b N = 164	Agricultural type	0.69	1	0.40
	Agricultural type [site]	23.31	18	0.18

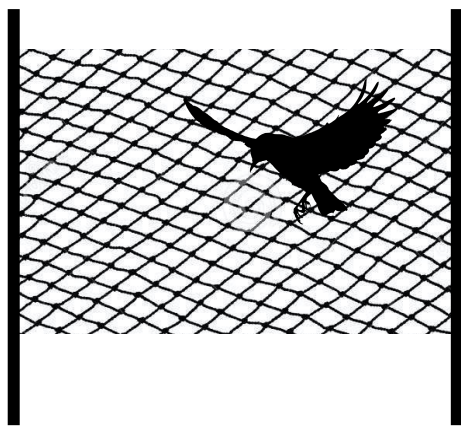
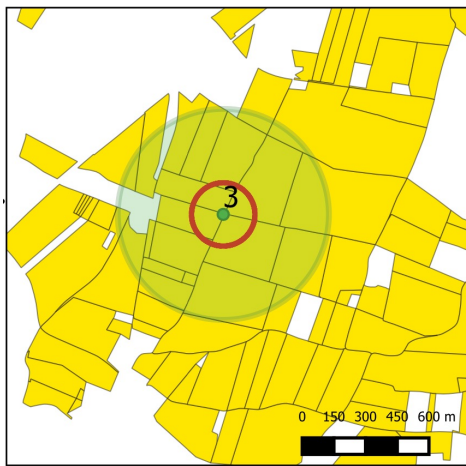
808
809
810
811

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

