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## **Impact of farming systems on agricultural landscapes and biodiversity: from plot to farm and landscape scales.**

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1 **Impact of farming systems on agricultural landscapes and biodiversity: from plot to**  
2 **farm and landscape scales.**

3 **Abstract**

4 Green-way policies in agricultural landscapes focus on ecological continuity between semi-natural  
5 elements (hedgerows, permanent grasslands, woods) and landscape heterogeneity. These policies  
6 suggest annual crops and temporary grasslands exhibit a negative or neutral impact on biodiversity.  
7 However, recent studies indicated the spatial continuities between different crops (spring vs. winter)  
8 showed positive impacts on biodiversity. These landscape patterns were directly related to farmers'  
9 decisions regarding the crops cultivated and where the crops were distributed spatially on the farm.  
10 The aim of the present study was to evaluate the impacts of different livestock farming system  
11 management types on crop patterns and associated biodiversity (carabid beetles) in agricultural  
12 landscapes. We combined empirical analyses of farmers' decision making and ecological data to  
13 develop a modeling framework simulating crop allocation and abundance of two different carabid  
14 beetle species groups (maize and woody species). Modeling included field, farm, and landscape  
15 levels. We simulated different scenarios, where two livestock farming systems, swine and dairy,  
16 were combined in different proportions (i.e. number of swine vs. dairy farms) in two agricultural  
17 landscapes with varied hedgerow densities. Simulations showed maize carabid species abundance  
18 was higher in swine production landscapes due to more frequent spatial continuities between spring  
19 and winter crops. In contrast, woody carabid species were more abundant in mixed landscapes  
20 (dairy and swine) under high crop diversity. For a given combination of livestock farming systems,  
21 simulated landscapes were highly variable in crop acreages and spatial continuities between crops.  
22 Our results emphasized the need to manage landscape at a collective level, where crop allocation  
23 decisions create more interfaces without modifying livestock farming system combinations.

24 **Keywords:** Agricultural landscape modeling, Biodiversity, Carabid beetle, Livestock,  
25 Heterogeneity, Mixed landscape

## 26 **1. Introduction**

27 Preventing further biodiversity losses in agricultural landscapes is an important social and economic  
28 issue, particularly due to societal expectations regarding the provision of ecosystem services, such  
29 as pollination and pest regulation from species at risk, e.g. *Apis mellifera*, *Rodolia cardinalis*  
30 (Kleijn and Sutherland, 2003; Le Roux et al., 2008; Millennium Ecosystem Assessment, 2005).  
31 Among the major causes responsible for the decline in biodiversity, habitat fragmentation  
32 (corresponding to a reduction in suitable species habitat and increased habitat isolation; Fahrig,  
33 2003) was inarguably identified as a main driver in species extinction (Fahrig, 2003; Krauss et al.,  
34 2010; Tilman et al., 2001). The connectivity of remaining suitable habitat fragments — defined as  
35 the degree to which the landscape facilitates or impedes species movements (Taylor et al., 1993) —  
36 is therefore considered particularly critical for species survival (Fahrig and Merriam, 1985, 1994;  
37 Moilanen and Hanski, 1998; Ricketts, 2001).

38 A variety of green-way policies have been developed and implemented in Europe and elsewhere to  
39 promote habitat connectivity in agricultural landscapes through the design of "ecological networks"  
40 (Bennett and Mulongoy, 2006). Existing policies primarily focus on the connectivity of semi-  
41 natural habitats (hedgerows, permanent grasslands, woods) (e.g. the Natura 2000 network in the  
42 EU), which was found crucial for many species survival (Bianchi et al., 2006; Billeter et al., 2008).  
43 Under these policies, the "matrix" composed of annual crops and temporary grasslands was  
44 expected to result in a negative or neutral impact on biodiversity. Some studies suggested the  
45 presence of annual crops with dense cover had a positive impact on woody species (see e.g.  
46 Fitzgibbon, 1997; Ouin et al., 2000). The connectivity of annual crops, which serve a role for  
47 species using cropped habitats during their life cycle was also reported, such as pollinators or  
48 natural enemies of crop pests (Burel et al., 2013; Maisonhaute, 2010; Varchola and Dunn, 1999;  
49 Vasseur et al., 2013). Because biotic and abiotic resources are ephemeral in annual crops, the  
50 survival of these species is expected to depend on their ability to colonise new suitable habitats to  
51 supplement or complement resources (Dunning et al., 1992). The temporal connectivity of crops,

52 such as winter and spring crops, which offer resources at asynchronous periods, might guarantee  
53 supplementation and complementation processes and therefore native species survival (Burel et al.,  
54 2013; Vasseur et al., 2013).

55 Papy (2001) showed annual crop connectivity in agricultural landscapes was directly related to  
56 farmers' decisions regarding the crops cultivated and where the crops were geographically located  
57 on the farm. In livestock farms, crop choice was associated with animal feeding management (Papy,  
58 2001). When several animal types were bred and include a dairy herd, the main objective was to  
59 produce fodder (i.e. primarily grass and maize) for dairy animals (Garcia et al., 2005). In dairy  
60 farms, the diet composition and field spatial organization (distance of fields to farmstead)  
61 influenced crop rotation choices (Brunschwig et al., 2006). The main factor determining crop  
62 rotation on swine farms was the presence of a feed production facility on the farm (Tersiguel et al.,  
63 2012). Tersiguel et al. (2012) reported swine farms grow primarily wheat and maize when feed  
64 production facilities were on the farm, whereas swine farms without feed production facilities grow  
65 a large diversity of winter crops and less maize. In addition to feed production, crop market prices  
66 (Reganold et al., 2011) and manure management (Ramonet et al., 2014) also played a role in crop  
67 rotation choices for all farming systems. Crop location on the farm depended on field  
68 characteristics, crop management requirements, and distance between field and facilities  
69 (Brunschwig et al., 2006; Maxime et al., 1995). The types and diversity of livestock farming  
70 systems associated with the field pattern and characteristics on farms might therefore be important  
71 drivers of crop surface area and spatial configuration, i.e. crop connectivity. However, to our  
72 knowledge, studies have not yet attempted to associate the agronomic drivers of crop patterns on  
73 biodiversity, which might be due to the challenges in experimentation on these factors: the farming  
74 system is a specific choice of a farmer and cannot be altered. Modeling the agricultural landscape  
75 resulting from crop organization by farmers is an alternative. Several landscape models have been  
76 developed in recent years, mainly based on statistical inferences (Dury, 2011). The models are  
77 largely derived from data mining of land cover databases, where the farm level is lacking. This

78 implies the models cannot integrate an explicit representation of a cropping plan decision rule at the  
79 farm level. Some models include the possibility to define several groups of fields, and for each,  
80 specific parameter are available to simulate land cover (e.g. Castellazzi et al., 2010), but for  
81 ecological analyses the models are not defined. However, a wide range of whole farm models have  
82 been developed to identify the best cropping plan to fit farmer objectives (Chardon et al., 2012;  
83 Pannell, 1996; Rotz et al., 1999; Rounsevell et al., 2003). Some of these models do not include a  
84 spatial representation of the cropping plan (e.g. Schils et al., 2007) and cannot be used to evaluate  
85 landscape configuration. However other models include a spatial representation of cropping plans,  
86 but i) produce only one optimized crop allocation at the farm level, and ii) do not allow aggregation  
87 of several farms within a landscape (e.g. Chardon et al., 2012). The role of agronomic factors  
88 should be explored by developing a model that describes the diversity of possible crop distributions  
89 within a farming system and not only an optimal model.

90 The objectives of this study were to evaluate the impact of different livestock farming management  
91 systems on landscape patterns related to crops and associated biodiversity using carabid beetles  
92 (Coleoptera, Carabidae) as the model species. Carabid beetles have been extensively studied in  
93 agricultural landscapes (Koivula, 2011; Kromp, 1999; Rainio and Niemelä, 2003) and they are  
94 known to respond to the effects of landscape composition or configuration related to semi-natural  
95 habitats (Billeter et al., 2008; Duflot et al., 2015; Puech et al., 2014) or land-use diversity (Ekroos et  
96 al., 2010; Maisonhaute et al., 2010). The following hypotheses were tested: i) the adoption of  
97 different livestock farming systems generated changes in landscape patterns observed in relative  
98 amounts of spring and winter crops and crop connectivity; ii) the observed changes were modulated  
99 by the spatial characteristics of farm fields; and iii) changes influenced carabid beetle species using  
100 cropped habitats, but not on species using semi-natural habitats. Our hypotheses were tested using a  
101 modeling framework, which simulated the diversity of agricultural landscapes based on crop  
102 allocation decision rules at the farm level and estimated biodiversity based on landscape

103 configurations. We chose two different livestock farming systems as a case study — swine and dairy  
104 — in hedgerow network landscapes (“bocage” landscapes) of Brittany (France).

105

## 106 **2. Materials and Methods**

107 Our landscape modeling framework combined plot (crop field or woody element, here hedgerow),  
108 and its landscape context (described in a circle centred on the plot, with varying radius sizes), the  
109 landscape unit level (defined here as a 500m radius circle), the individual farm level, and the level  
110 of several farms (eight farms in total) (Figs. 1 and 2). The model combined two ecological models  
111 predicting carabid abundance at the plot level according to plot landscape context (A), a crop  
112 allocation model at farm level integrating agronomic decisions and constraints (B), and digitized  
113 maps of real landscapes including several farm territories (C) to predict and assess landscape  
114 patterns and ecological effects produced under different scenarios of farming system combinations  
115 (D and E). The combination of ecological models with farming scenario and landscape analysis  
116 simulations were conducted in APILand virtual laboratory for landscape modeling (Boussard et al.,  
117 2010). This modeling platform includes the following: i) a meta-model of landscape representation  
118 in space, time, and theme, which facilitates a non-agricultural matrix (roads, buildings, forests, and  
119 hedgerows) and farm territory combination; and ii) temporal simulation tools to combine agronomic  
120 and ecological models.

121

### 122 **2.1. Ecological and agronomic models**

#### 123 **2.1.1. Predictive models of carabid beetle abundances: the 'maize' & 'woody' models (A)**

124 Statistical modeling was performed to simulate carabid beetle abundance at the plot level (crop field  
125 or woody elements) based on the characteristics of plot landscape contexts (amount, spatial  
126 connectivity, and cultivated and uncultivated habitat heterogeneity) (see Appendix A for more  
127 details). Multi-model inference (Burnham and Anderson, 2002) applying Mixed Generalized Linear  
128 Models (GLMM) was used to link existing carabid data and landscape metrics (calculated in

129 different radius sizes) in landscape case studies in Brittany, Western France (Duflot et al., 2014,  
130 2015, 2016). Analyses were performed for two different indicator carabid species groups, i.e.  
131 species associated with woody habitats ('woody' model) and species associated with maize crops  
132 ('maize' model). The final statistical models identified for the two carabid groups (best models with  
133 the lowest Akaike's information criterion (AICc)) were the following:

134 • Maize species:  $N_{maize} = e^{(4.98 + (6.78e^{-04} \times E_{WIC-MA500}) - (7.05e^{-06} \times C_{W500}))}$

135 where  $N_{maize}$  is the abundance of maize species,  $E_{WIC-MA500}$  is the edge length between maize and  
136 winter crops in a 500 m radius and  $C_{W500}$  is the connectivity of woody habitats in a 500 m radius.

137 • Woody species:  $N_{woody} = e^{(5.43e^{-01} + (3.49e^{-04} \times C_{W50}) + (6.80e^{-05} \times C_{G50}) + (1.37 \times SHDI_{50}))}$

138 where  $N_{woody}$  is the abundance of woody species, and  $C_{W50}$ ,  $C_{G50}$ , and  $SHDI_{50}$  represent respectively  
139 woody habitats and grasslands connectivity and land-use Shannon diversity in a 50 m radius.

140 The two carabid models explained a good percentage of variation in carabid abundances (pseudo-R<sup>2</sup>  
141 = 0.48 for both models) (Appendix A). The predictive capacity of the two statistical models was  
142 assessed by i) calculating a measure of Root Mean Square Error of Prediction (RMSEP) with k-fold  
143 cross-validation (where k = 10); and ii) fitting observed and predicted values for both models. The  
144 'maize' model had a RMSEP of 80.3 individuals, which corresponded to 33% of the median  
145 observed abundances of maize species (min = 9, max = 494). The 'woody' model had a RMSEP of  
146 20.5 individuals, which corresponded to 49% of the median observed abundances of woody species  
147 (min = 0, max = 83). The comparison of observed and predicted abundances showed that both  
148 models tended to underestimate predicted abundances compared to observations (Figure 1,  
149 Appendix A). It also showed for both models a correct, overall fit between predicted and observed  
150 values ('maize' model: pearson correlation R = 0.64; 'woody' model: R = 0.58), but weaker  
151 relationships for the highest abundance values (above median values) (Figure 1, Appendix A).

152 The two models were integrated in the APILand virtual laboratory as the 'maize' and 'woody'  
153 models.

154

### 155 **2.1.2. Model of crop allocation: the *CAPFarm* model (B)**

156 A crop allocation problem solver was developed to simulate crop allocations over years at the farm  
157 level. The crop allocation problem was defined by Akplogan et al. (2013) as "a spatiotemporal  
158 planning problem in which crops are assigned to fields over a finite time horizon" and we solved the  
159 problem by assigning "crops (values) to fields (variables) over a finite time horizon" (Akplogan et  
160 al., 2013).

161 We developed our crop allocation problem solver — '*CAPFarm*' — applying the following steps: i)  
162 the JAVA *Choco3* Constraint Satisfaction Problem (CSP) solver (Prud'homme et al., 2014) was  
163 employed to build a crop allocation problem solver in the APILand platform; ii) field data from  
164 farm surveys in Brittany (Western France) were applied to conduct a first parameterization of the  
165 model integrating crop distribution constraints observed in livestock farming systems in the area  
166 investigated (constraint list in Table 1) (Roche et al., 2013); two farms with different crop rotations  
167 and location rules were considered at this stage, i.e. a swine farming system ('*swine*') and a dairy  
168 farming system ('*dairy*'); and iii) crop allocation simulations were run for the two farms to generate  
169 maps of possible crop allocation during five consecutive years on surveyed farms; the maps were  
170 verified by farmers to modify and/or validate crop rotation and location rules.

171 The final model parameterization integrated the following rules: i) the '*swine*' system was  
172 characterized by large geographic surface areas cultivating cereals (including rape seed), no  
173 temporary grassland, short crop rotations, and only 50% usable agricultural area (UAA) required for  
174 the minimum cropped area; and (ii) the '*dairy*' system was characterized by distance from pasture  
175 fields to milking area (farmstead) constraints, large geographic surface areas cultivating temporary  
176 grassland and maize for forage self-sufficiency, long crop rotations including cereal crops, and 90%  
177 of the UAA required for minimum cropped area. The final set of rules for each case system is  
178 shown in Table 1.

179

### 180 **2.2. Selection of case study sites: the 'open' & 'dense' landscape units (C)**

181 We tested the sensitivity of our simulation results to “bocage” characteristics by selecting two  
182 landscape units (and their associated farms) with different densities of woody elements. The  
183 landscape units were defined within 500 m radii circles to run both ecological model simulations  
184 (see part 2.1). We used two existing GIS databases to produce maps with realistic landscape  
185 composition and configuration regarding arable fields, roads, buildings, and woody elements: i) a  
186 regional map of woody elements (hedgerows and woodlots) produced by the CNRS-LETG  
187 laboratory (Hubert-Moy et al., 2012); ii) the land parcel identification system (LPIS), where farm  
188 territories and arable islets are mapped. Moving window analyses were applied to these maps using  
189 the *Chloe2012* software (Boussard and Baudry, 2014) to select two landscape units with varied  
190 densities of woody elements, but with a similar number of farms (eight) and UAA percentage (90 %  
191 of the circle areas). Finally, we digitized fields within LPIS islets and identified a farmstead for  
192 each farm added from aerial photographs and satellite images. This resulted in production of two  
193 divergent virtual landscape units based on real landscape composition and configuration: an 'open'  
194 landscape unit with very low density of woody elements (0.5 % of the 500 m radius circle area) and  
195 a 'dense' landscape unit, with higher density of woody elements (16.3 % of the 500 m radius circle  
196 area). The farms composing those landscape units are noted O1 to O8 for open landscape unit and  
197 F1 to F8 for dense landscape unit.

198

### 199 **2.3. Virtual experiment plan for landscape and ecological simulations (D)**

200 The effects of crop allocation on carabid abundance was defined by simulating the following virtual  
201 experiment plan applied to the two case study landscape units (*open* and *dense*):

- 202 • At the farm level and for each of the eight farms, which composed each landscape unit, we pre-  
203 simulated crop allocation for both farming systems, i.e. 'swine' and 'dairy' using the *CAPFarm*  
204 solver parameterized with validated sets of agronomic constraints (B). One thousand simulation  
205 iterations were run to obtain several crop allocation over 10 years for each farm and each  
206 farming system. Due to variable constraint levels resulting of the combination farm / farming

207 system, we obtained from 9 to 810 successes over the 1000 iterations. These successful  
208 iterations allowed the generation of various possible crop distribution patterns regarding each  
209 set of agronomic constraints.

210 • At the all farms level, we simulated 256 scenarios representing all combination possibilities of  
211 two farming systems across eight farms (from zero to eight farms in swine vs. dairy farming).  
212 For each scenario, 250 simulation iterations were performed to ensure sufficient robustness in  
213 the modeling results and allow sufficient comparisons among scenarios. Simulations were  
214 conducted by randomly selecting one of the pre-simulated crop allocations for each farm over  
215 10 years. This resulted in the production of 10 x 250 x 256 simulated landscape maps for each  
216 landscape unit. These sets of simulated landscape maps are henceforth referred to as 'open  
217 landscape' or 'dense landscape'.

218 • At the plot level, the '*maize*' and '*woody*' models were run using landscape metrics calculated on  
219 simulated landscape units to predict carabid abundances at the plot level based on its landscape  
220 context. For the '*maize*' model, landscape metrics were calculated within a 500 m radius around  
221 the central arable field of each landscape unit. Calculations were conducted only for years  
222 where these central fields were cultivated as maize according to crop allocation model  
223 simulations. The '*woody*' model had a limited spatial extent (50 m) used in the metric  
224 calculations. Therefore, running the simulations for a central woody element (hedge) at each  
225 landscape unit could not ensure sufficient variability for plots' spatial context among scenarios.  
226 Subsequently, the '*woody*' model was run on each year for several woody elements based on the  
227 density of woody elements at each landscape unit (five at the '*open*' landscape unit and 29 at the  
228 '*dense*' landscape unit).

#### 229 **2.4. Data analyses (E)**

230 As agronomic rules contains some time dependencies (i.e.: crop return time), not all the rules are  
231 effective at the start of the simulation. The first five years (over the ten simulated) were therefore as  
232 an initialization and stabilization phase and were excluded from analyses. On the remaining five

233 years, we considered each year of a simulated landscape unit as a statistical individual. This resulted  
234 in 1250 statistical individuals (i.e. simulated landscapes-year) for each scenario.

235 We analysed the variation in cultivated area amongst scenarios, by calculating the surface area of  
236 crops (averaged over the 1250 simulated landscapes-year) at the all farms and landscape unit levels.

237 We distinguished three categories of crops: (i) winter crops (WIC) grouping wheat, oil seed rape  
238 and barley, (ii) spring crops (SC) grouping maize-corn and maize-silage and (iii) grassland (GL)  
239 grouping permanent and temporary grassland, pasture and lucerne.

240 The impacts of farming systems scenarios on carabid abundance predicted by 'maize' and 'woody'  
241 models at the plot level were analyzed by testing the effects of the following two variables: i)  
242 number of farms under dairy production (0 to 8 farms); and ii) percentage of geographic surface  
243 area in each landscape unit managed under dairy production (see part 2.3.).

244 In a last step, we analyzed farm contributions to variation in carabid beetle abundance predicted by  
245 the 'maize' model using a specific analysis. We focused on the 'maize' model, as only one  
246 calculation was required per simulated landscape, in contrast to the 'woody' model (see part 2.3.).

247 Focusing on the 'maize' model allowed us to limit the potential factor number able to modify the  
248 farm contributions to variation in carabid abundance predicted by ecological models. The  
249 contribution of an individual farm  $i$  to the variation in predicted abundances of maize carabids was  
250 assessed in several steps. First, the 256 initial scenarios were split into 128 sets of two modalities,  
251 where for each set, the individual farm  $i$  was either under swine farming ('S') or dairy farming ('D') ,  
252 whilst the other seven farms had fixed farming type. The 128 sets corresponded to the whole  
253 possibilities regarding the type of farming system attributed to each of the other seven farms (as  
254 explained in section 2.3). For instance, the following are three sets created to calculate the  
255 contribution to the variation in predicted abundances of maize carabids of farm #1: {SDDDDDDD ;  
256 DDDDDDDD}, {SDDDDDDS ; DDDDDDDS}, {SDDDDSD ; DDDDDSD} (where each  
257 letter represents an individual farm). In a second step, we noted  $N[S]_x$  the simulated abundance of  
258 maize carabid beetles for the set  $x$  with the swine modality and  $N[D]_x$  for the dairy modality. The

259 contribution  $C_{set_x}$  of the farm  $i$  to the variation in carabid abundances for one set  $x$  was estimated as  
260  $C_{set_x} = N[S]_x - N[D]_x$ . The final contribution of farm  $i$ ,  $C_i$  was the average contribution of all sets  $x$ :

261 
$$C_i = \frac{1}{128} \sum_{x=1}^{128} (N[S]_x - N[D]_x).$$

262 Because maize carabid abundances are related to edge length between winter and spring crops we  
263 calculated several descriptors of farm characteristics within the landscape units to explain their  
264 contribution to variation in carabid abundances (Table 2): i) the geographical area, ii) the total edge  
265 length, with the hypothesis that farm contribution is high when the total edge length of the farm in  
266 the landscape unit is high, and iii) grassland area (from minimum to maximum obtained within  
267 replications) with the hypothesis that the contribution of a farm will be high if it has large grassland  
268 areas when it is under dairy farming (since it will result in a large decrease of winter crop area when  
269 changing from swine to dairy production).

270

## 271 **3. Results**

### 272 **3.1. Effect of farming systems on cropping plan**

273 Differences in crop surface areas (averaged over the 1250 landscapes-year) at the all farms scale  
274 based on percentage of all farms geographic surface area under dairy farming in both landscape  
275 units is shown in Figure 3. In each landscape unit, the transition from swine production to dairy  
276 production resulted in the same trend: a decrease in winter crop areas and increase in grasslands  
277 areas. Dense and open landscape units differed in grassland areas in the swine farm scenario only (0  
278 % of area under dairy farming). This result was due to the smaller field size in the dense landscape  
279 unit, which resulted in a higher number of fields used as permanent grassland compared with the  
280 open landscape unit. Differences in grassland percentages between the two landscape units (67 % of  
281 all farm areas in both landscape units) were not observed in the dairy only scenario (100 % of area  
282 under dairy farming), the permanent grassland area was lower than the grassland area required by  
283 these systems. Consequently, the increased grassland percentage in dense landscape unit was lower

284 than in the open landscape unit. Within a scenario, the variability in crop surfaces was low  
285 (variation coefficient below 15 %).

286 Differences in each crop surface at the landscape unit level (averaged over the 1250 landscape-year)  
287 based on percentage of the geographic area managed by dairy farms (a) or number of dairy farms  
288 (b) is depicted in Figure 4. Results indicated crop differences were the same compared with the all  
289 farms scale. Variability within scenario was higher than that observed at the all farms scale. The  
290 variation coefficient for all spring crops remained high in all scenarios (~ 30 %). Spring crops are  
291 necessary in both farming systems and no specific agronomic constraints are required on the  
292 seedlings, therefore increased variability was observed related to a scale effect. The simulated  
293 grassland percentage is correlated to the percentage of the landscape unit area managed by dairy  
294 farms but locally two scenarios with almost the same percentage of the landscape unit managed by  
295 dairy farms (i.e. 50%) could have very different grassland percentage (i.e. from 15 to 30%) (Fig.  
296 4a). The differences were due to the spatial organization of farms fields and the farmstead position.  
297 Some farmsteads were within the landscape unit and so pastures were more often seeded within  
298 landscape unit. For farms with facilities outside the landscape unit, fields managed within landscape  
299 unit were more often in winter or spring crops and not grasslands. The wide range of variability in  
300 cropping plans for a fixed number of dairy or swine production farms is shown in Figure 4b.  
301 Differences in the farm area managed at the landscape unit and the previously explained field  
302 organization explain these observations.

303

### 304 **3.2. Predictions of carabid abundance in simulated landscapes**

305 Predicted abundance of maize and woody carabid species in both landscape units, derived from the  
306 number of dairy farms (one to eight) and the geographic surface area covered by dairy production is  
307 depicted in Figure 5.

308 Different responses were found between the two carabid species groups and landscape units.  
309 Woody species abundance varied non-linearly based on the number of dairy farms in both

310 landscape units (polynomial regression, open landscape unit:  $R^2 = 0.46$ , F-statistics = 108.0,  $P <$   
311 0.001; dense landscape unit:  $R^2 = 0.37$ , F-statistics = 76.1,  $P < 0.001$ ) (Fig. 5.1a). Responses were  
312 maximized for different scenarios depending on landscape, i.e. for scenarios with six to seven dairy  
313 farms (over a total of eight farms) in the open landscape unit and for scenarios with two to three  
314 dairy farms (over a total of eight farms) in the dense landscape unit. In contrast, maize species  
315 abundance decreased with increasing number of dairy farms in both landscape units (linear  
316 regression, open landscape unit:  $R^2 = 0.42$ , F-statistics = 181.2,  $P < 0.001$ ; dense landscape unit:  $R^2$   
317 = 0.38, F-statistics = 158.8,  $P < 0.001$ ) (Fig. 5.1b). In scenarios where dairy farming dominated,  
318 edge length between maize and winter crops was reduced. Hedgerow length did not vary within  
319 each landscape unit, therefore decreased maize species abundance was due to decreased edge length  
320 between maize and winter crops (cf. 2.1.1.). The decreased abundance of maize species was  
321 reduced in dense compared with open landscape units, in relationships with the negative effect of  
322 the connectivity of woody elements on maize carabid species.

323 Results regarding the surface area covered by dairy production (Figure 5.2a and 5.2b) showed that  
324 abundances of woody species vary non-linearly according to the proportion of dairy farming in both  
325 landscape units (polynomial regression, *open* landscape unit:  $R^2 = 0.37$ , F-statistics = 50.1,  $p < 0.001$ ;  
326 *dense* landscape unit:  $R^2 = 0.81$ , F-statistics = 557.8,  $p < 0.001$ ). Regarding maize species, carabid  
327 abundances were aggregated into two distinct clusters, but without relationships with the overall  
328 variation in the proportion of surface area under dairy production in both landscape units. It  
329 suggests the influence of other factors than the only proportion of surface area under dairy farming.  
330 However, within each cluster, carabid abundances tended to decrease with the proportion of dairy  
331 farming in the landscape.

332

### 333 **3.3. Farm contribution to the variation in carabid abundance predicted by the 'maize' model**

334 The 'maize' model farm contribution varied from 0 to 50.4 in the dense landscape unit and from 0.1  
335 to 230.1 in the open landscape unit (Table 2). In both landscape units, the highest contributions

336 were associated with large areas farmed at a landscape unit. Five farms with more than 10 ha in a  
337 landscape unit were major contributors to variation in carabid abundance. However, data showed no  
338 linear relationship between farm contribution and farm area within landscape unit (see farms O4,  
339 O8 in open landscape unit and F7 in dense landscape unit). Spearman correlation coefficients  
340 indicated long lengths of variable edges (i.e. each field along the edge are cultivated) and increased  
341 grassland frequencies were correlated with high contributions (Table 3). More precisely, grassland  
342 frequency was more determinant in the open landscape and variable edge length was more  
343 determinant in the dense landscape. Thus, the results indicated O8 did not contribute despite  
344 farming 7.3 ha in an open landscape unit, O8 showed the absence of variable internal edges, and  
345 increased grassland areas were rare (see percentile p80). F7 exhibited comparable variable edge  
346 length to F5 and lower relative to F3, which explained its close contribution to F5 yet lower than  
347 F3.

348

#### 349 **4. Discussion**

##### 350 ***4.1. Effects of farming systems on landscape pattern and carabid abundance***

351 In our study, we simulated carabid abundances in fields or woody elements using statistical  
352 modelling. The two models built had a good explicative value (pseudo  $R^2 = 0.48$ ) but the RMSEP  
353 analyses revealed high errors of predictions of the models. For both models, these errors were  
354 higher for the highest values of predicted abundances. The higher errors of predictions for the  
355 '*woody*' model suggests that variations in predicted abundances by this model should be interpreted  
356 carefully. However, we assumed that the models remained useful for a qualitative assessment of  
357 contrasted farming and landscape pattern scenarios for the two carabid groups.

358 Our overall results showed abundance of the two carabid groups differed due to landscape pattern  
359 effects as a function of farming system but the two models revealed different responses. Maize  
360 carabid species experienced positive abundance influence under swine farming system dominance  
361 landscapes (i.e. a 500 m radius around crops). This was associated with increased winter crops

362 cultivated areas in swine systems, which resulted in increased edge lengths between winter crops  
363 and spring crops. In spite of the high prediction errors (33%) of the '*maize*' model, the important  
364 contrast in the predicted abundances between the most extreme farming scenarios in the open  
365 landscape unit (about 750 individuals in the 100% swine scenarios *vs.* 200 individuals in the 100%  
366 dairy scenarios) suggested a significant effect of farming systems on maize carabid beetles in these  
367 landscapes. Vasseur et al. (2013) suggested crop spatial connectivity might be an important driver  
368 of arthropod maintenance in cultivated habitats of agricultural landscapes, as it determined the  
369 spatio-temporal continuity of resources for these species. At the local scale, Burel et al. (2013)  
370 showed carabid beetles moved between adjacent, asynchronous crops (winter and spring), which  
371 suggested spatial continuities between seasonal cultivated crops favored resource complementation  
372 processes (Dunning et al., 1992) for crop carabid species. Such processes might explain the positive  
373 edge length effects between asynchronous crops on crop carabid beetle abundance at the landscape  
374 scale observed in our study. Duflot et al. (2016) reported crop configurations decreased carabid  
375 abundance, which differed from our results. Duflot et al. (2016) examined an overall carabid beetle  
376 community in cultivated wheat fields and total, gamma biodiversity, where we investigated maize  
377 carabid species groups in cultivated maize and local, alpha biodiversity, variables, which likely  
378 explains the different results observed between our studies. Our results emphasized the importance  
379 of crop diversity and configuration in biodiversity, as reinforced by previous studies (e.g. Duflot et  
380 al., 2014).

381 By contrast, abundances of woody carabid species varied non-linearly according to the number of  
382 dairy farms and the proportion of area under dairy farming. Abundances of these carabid species  
383 were slightly higher in landscapes with both types of farming systems (i.e. with similar relative  
384 surface areas of spring crops, winter crops and grassland) than in landscapes with specialization of  
385 production (either towards dairy or swine production). A positive effect of land-use diversity on  
386 woody species at a fine spatial scale (i.e. in a 50 m radius around hedgerows) served to explain this  
387 result. Fahrig et al. (2011) provided evidence that land-use diversity reflected compositional

388 landscape heterogeneity. Additional study indicated it a key driver of biodiversity in agricultural  
389 landscapes (Benton et al., 2003; Fahrig et al., 2011) and diverse land-use showed beneficial effects  
390 on carabid communities (Batáry et al., 2007; Millán de la Peña et al., 2003). However, these results  
391 should be interpreted with caution since the range of variation in predicted abundances is very low  
392 (a few individuals) and the errors of prediction of the 'woody' model are high (49%). This  
393 underlines the difficulty to explain properly the presence and abundance of species such as woody  
394 carabid species that are often very scarce in actual agricultural landscapes.

395 If the effects of farming system processes seemed similar in both landscape units, results indicated  
396 the range of variation in carabid abundance across scenarios was smaller in the dense (complex)  
397 landscape relative to the open landscape. This result can be compared to the mitigation role in  
398 landscape complexity to the intensification effect on biodiversity (Tscharntke et al., 2005).

#### 399 ***4.2. Farm contribution to variation in predicted carabid abundances***

400 Our modeling design was successful in elucidating the importance of individual farm level to  
401 explain variations in abundances of maize carabid beetles in the agricultural mosaic. The variability  
402 of contribution to deviation in predicted carabid abundance among farms was related to farm size,  
403 but also to the probability to seed grassland in dairy systems and to the edge length between fields  
404 where crops were sown. Brunschwig et al. (2006) and Thenail and Baudry (2004) identified a  
405 relationship between grassland seeding in dairy systems and field distance to the farmstead.  
406 Farmstead location to evaluate farm influence on predicted carabid abundance in a defined spatial  
407 area was clearly identified in these and our study. However, databases would not provide the  
408 farmstead location due to confidentiality clauses (INSEE, 2010) which limits the possible use of  
409 such database to identify the main farms able to increase the carabid beetle abundance in a specific  
410 area. In our simulations, we controlled farmstead location and analyzed location role to farm  
411 contribution to variation in predicted carabid abundance. Farms with the farmstead close to or  
412 within the processing landscape unit exhibited higher contributions to variation than farmsteads  
413 with a greater distance to processing. Factors responsible for differences in farm contribution to

414 variability between landscape units can be explained by landscape structural differences. Indeed,  
415 dense landscape unit revealed large surface areas of permanent grasslands and high hedgerow  
416 lengths, which limited the edges or interfaces between crop fields. However, these remaining  
417 interfaces between crop fields in the dense landscape unit were individually more important for the  
418 abundance of crop carabid beetle than crop fields interfaces in the open landscape unit. The  
419 interface length criterion was therefore more important at the farm level in the dense landscape  
420 compared with the open landscape.

421

#### 422 *4.3. Implications for biodiversity management in agricultural landscapes*

423 Predicting species abundances in agricultural landscapes using statistical modeling has limitations  
424 due to the uncertainty of predictions of ecological models (Barry and Elith, 2006). Although our  
425 models were built using an extensive dataset, there are still additional drivers of carabid abundances  
426 that could improve the predicting ability of models. However, our results on maize carabid species  
427 suggest that some specific organization of annual crops in space, maximizing the edges between  
428 asynchronous crops, could increase the abundances of these species. Presently, green way policies  
429 focus on the conservation of existing networks of semi-natural habitats. The present study suggests  
430 that farmers might contribute to create cropped green veining for the biodiversity associated to the  
431 agricultural mosaic. Our modeling approach allowed highlighting the possible contribution of  
432 farming systems and individual farmers to generate landscape configurations that are important for  
433 crop carabid species. These landscape configurations could result of localization of asynchronous  
434 crops on juxtaposed fields by an individual farmer. If our results showed this localization is possible  
435 one year, it should be tested over several years by including a new rule in our sets. As the field  
436 interfaces are often longer with fields of other farms than within the farm due to fragmentation of  
437 farms' land, another solution would be the coordination among farmers in association with other  
438 stakeholder types. For example, a group of farmers, the mayor, and a watershed advisor reduced the  
439 risk of erosion by engaging in a dialogue regarding grass strips, storage ponds, and an intercrop

440 management period (Souchère et al., 2010). For biodiversity management, this type of solution  
441 should consider crop localization, under consultation with a landscape planner. Indeed, crop spatial  
442 organization is easier to understand at a collective scale, rather than individually due to the spatial  
443 constraints at the farm scale (e.g. farmstead distance, soil quality, accessibility, among other  
444 factors). Green way policies do not include collective responses, which have to pass through  
445 different mechanisms. For example, Lucas et al. (2015) described an enhancement of collective  
446 farming and several farmers already engaged in collective cropping plans (Martin et al., 2015),  
447 which should be viewed as an opportunity to improve biodiversity at landscape scales.

448

## 449 **5. Conclusion**

450 Our multi-level and agro-ecological modeling framework facilitated the evaluation of different  
451 farming system (dairy and swine) impacts on landscape patterns and carabid beetle abundance. We  
452 showed the over-representation of swine farming resulted in an increased edge length between  
453 maize and winter cereals and consequently enhanced abundances of maize carabid beetles. Both  
454 farming systems seemed necessary to favor woody carabid beetles. Moreover, our results showed,  
455 given a set of farming systems in a landscape, variability in crop patterns and edge length between  
456 winter crops and spring crops emerged. This indicated farmers have possibilities to modify crop  
457 allocation with the objective to increase landscape patterns in relationship to biodiversity issues,  
458 while maintaining their production objectives. Therefore, we recommend the following: i) crop  
459 allocation modifications at the farm level, e.g. decrease large field size by dividing fields and  
460 increase potential interfaces, increase field accessibility to animals from the farmstead; and ii)  
461 explore modifications at a collective level, since landscape patterns result from several farmers'  
462 decisions. Currently, these solutions are not integrated in policies aiming to promote biodiversity, as  
463 green veining.

464

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470

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- 634

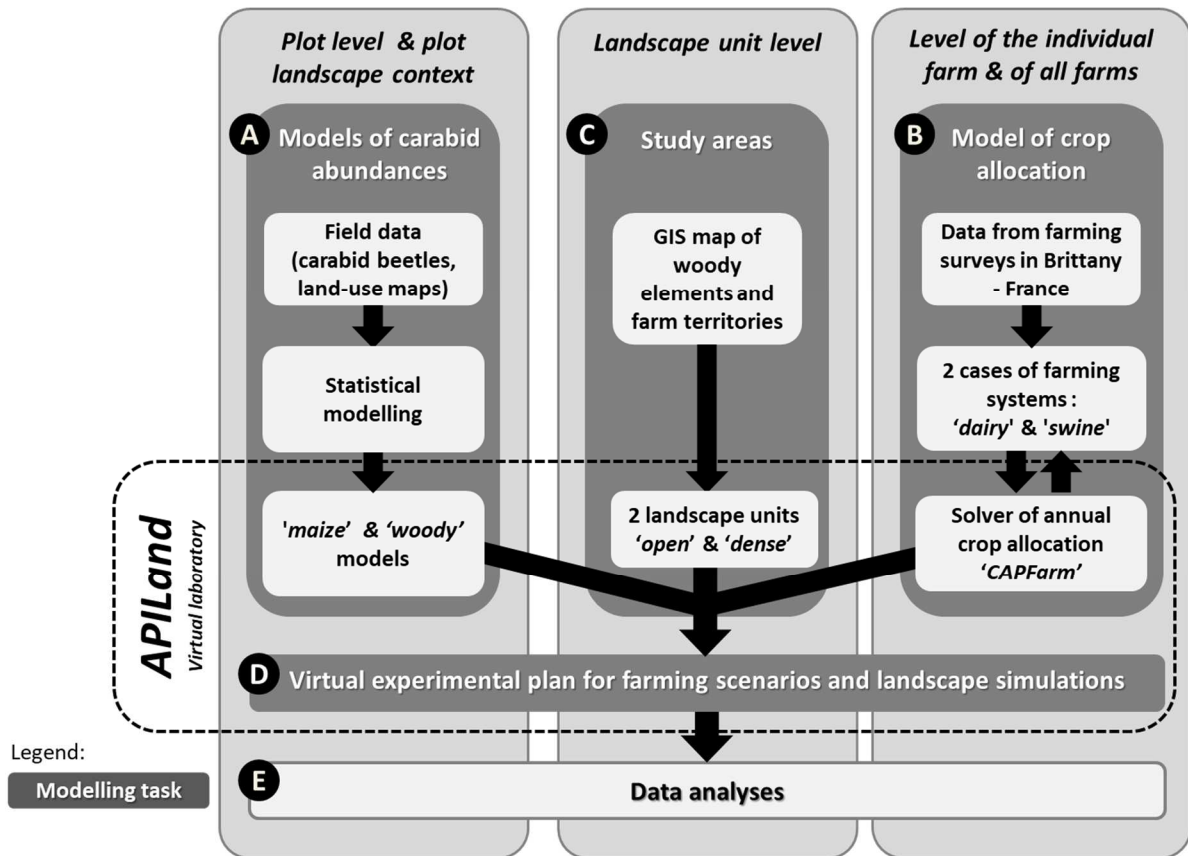


Figure 1: Overall view of the modelling approach used to simulate the diversity of agricultural landscapes based on crop allocation decision rules at farm level and to estimate biodiversity according to landscape configuration.

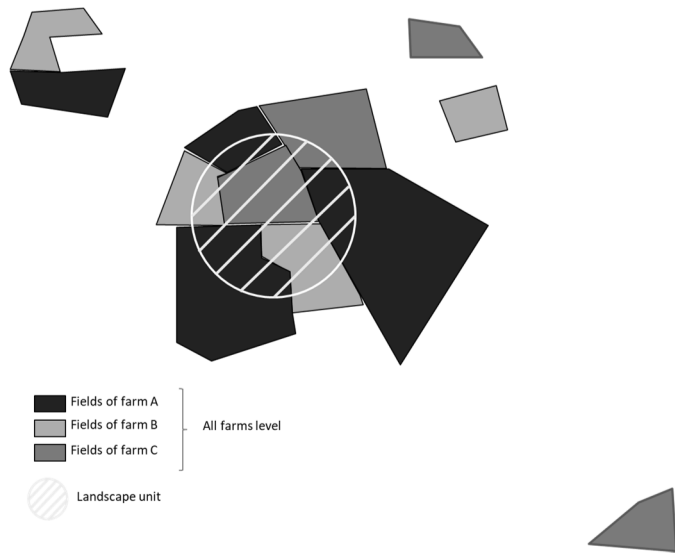


Figure 2: Landscape unit and farm / all farms levels considered in the modelling approach.

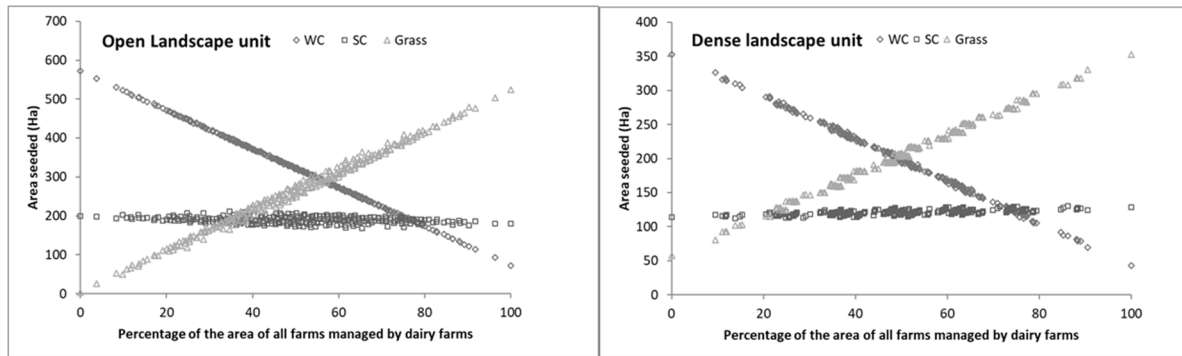
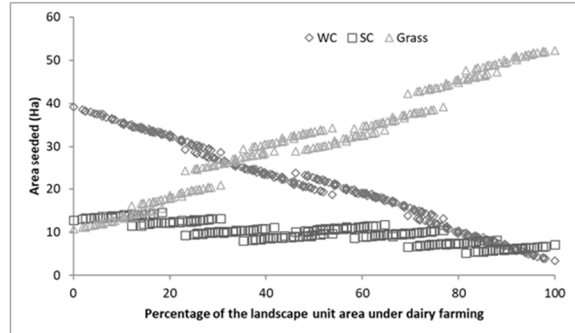
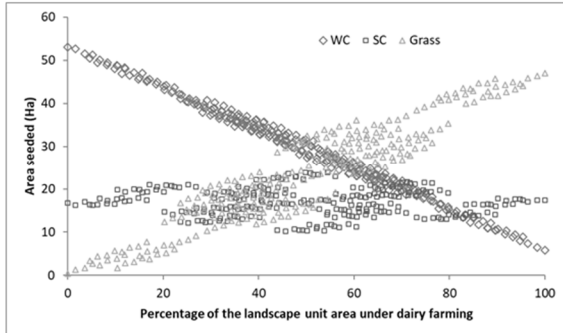


Figure 3: Averaged surface area (over the 1250 simulated landscapes x years) of winter crops (WC), spring crops (SC) and grassland (Grass) at the all farm level according to the percentage of the geographical area of all farms under dairy farming (left: *open* landscape unit, right: *dense* landscape unit).

## Open Landscape unit

## Dense Landscape unit

a/ Area seeded in landscape unit according to the percentage of the area managed by dairy farm



b/ Area seeded in landscape unit according to the number of dairy farm

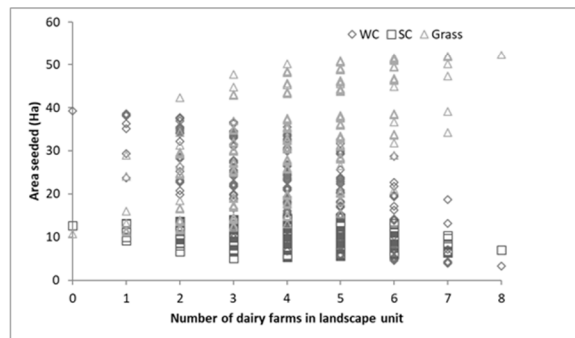
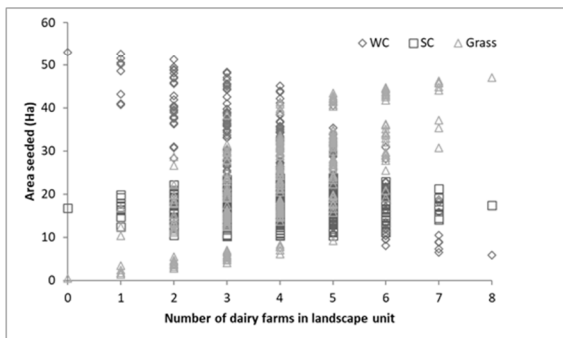
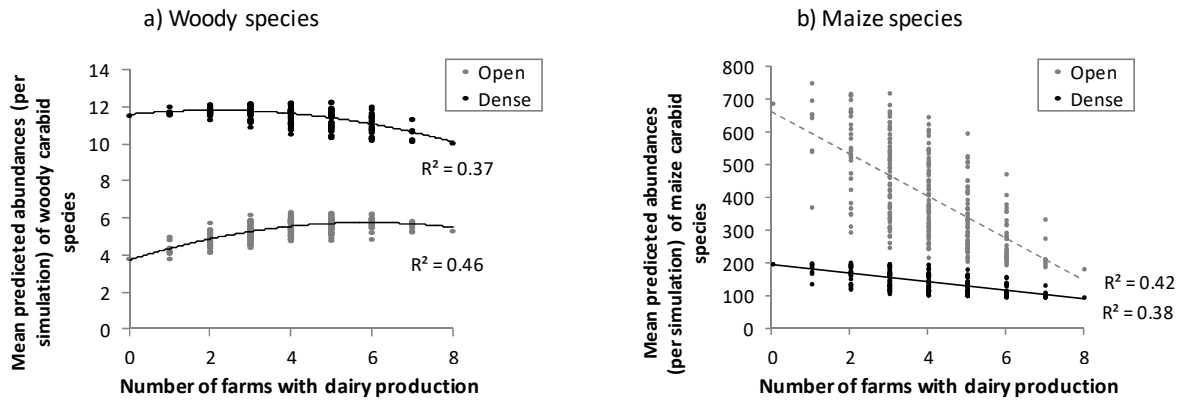


Figure 4: Average surface area (over the 1250 simulated landscapes x years) of winter crops (WC), spring crops (SC) and grassland (Grass) at the landscape unit level according to (a) the percentage of area under dairy farming and (b) the number of dairy farms in the *open* and *dense* landscape units.

## 1) Predicted abundances according to number of dairy farms



## 2) Predicted abundances according to surface area with dairy production

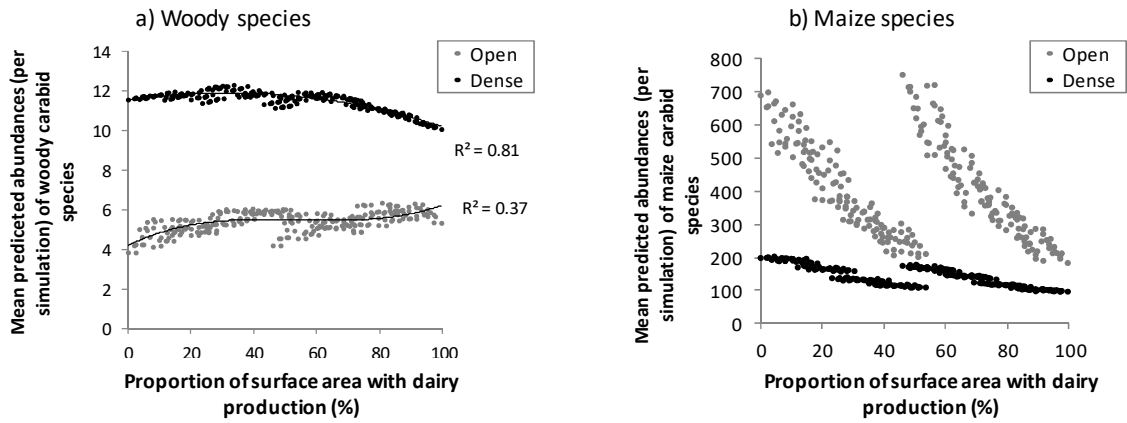


Figure 5: Predicted abundances of woody (a) and maize (b) species according to 1) the number of dairy farms and 2) the proportion of surface area under dairy farming in the dense and open landscape units.

Table 1: Set of rules in Swine and Dairy farming systems for each crop.

Group	Crop	Code	Allowed previous crop	Field size	Min total area	min return time	max rep.	min dur.	max dur.	never on	Distance from farm's head	
SFS	Maïze-Corn	MC	WH-BA	>0.5ha	max (5ha ; 5% UAA)	2	0	-	1	-	-	
	Wheat	WH	MC-RA	>0.5ha	max (5ha ; 10% UAA)	2	0	-	1	-	-	
	Barley	BA	WH	>0.5ha	max (5ha ; 5% UAA)	3	0	-	1	-	-	
	Rape oil seed	RA	WH-BA	>0.5ha	max (5ha ; 10% UAA)	3	0	-	1	Drained plot	-	
	Permanent Grassland	PG	PG	<0.5ha	-	-	-	-	-	-	-	
<b>Maize</b>	-	<b>MA</b>	-	<b>&gt;0.5ha</b>	<b>30% UAA</b>	-	-	-	-	-	-	
Maize	Maize-corn	MC	LO-PA-MA-WH-LU	-	-	-	3	-	1	-	> 400m	
Maize	Maize-Silage	MS	LO-PA-MA-WH-LU	-	-	-	1	-	1	-	< 400m	
<b>Weed</b>	-	<b>WE</b>	-	-	<b>33% UAA</b>	-	-	-	-	-	-	
DFS	Weed	Lolium	LO	MA-WH	>0.5ha	-	-	0	5	7	-	< 5000m
	Weed	Pasture	PA	MA	>0.5ha	16,5% UAA	2	0	5	10	-	< 400m
	Weed	Permanent Grassland	PG	PG	<0.5ha	-	-	-	-	-	-	-
-	Wheat	WH	MA-LU	>0.5ha	max (2ha; 7% UAA)	-	-	-	1	-	-	
-	Lucerne	LU	WH	>0.5ha	max (2ha; 5% UAA)	8	-	3	4	-	> 400m	

SFS: Swine farming system; DFS: Dairy farming system; UAA: Usable Agricultural Area; Return time is the number of years to wait between two sowings of the same crop on a same field; Max rep: Maximum number of successive seeding of a same crop on the same field; min dur. and max dur.: Minimum and maximum duration of crop.

Table 2: Contribution of farms to the variation in maize carabid abundances in both landscape units and main characteristics of farms.

Landscape unit	Farm	FC	UAA-S (ha)	FI (m)	VI(m)	VI-IN (m)	Min (ha)	p20 (ha)	Mean (ha)	p80 (ha)	Max (ha)
Dense	F6	0.0	1.5	605	0	0	0.0	0.0	0.7	1.5	1.5
	F8	1.2	1.6	557	134	0	0.0	0.0	0.4	1.2	1.2
	F1	1.4	1.2	514	99	0	0.0	0.0	0.5	0.9	0.9
	F4	4.9	5.0	2232	561	0	0.0	1.5	2.5	3.4	4.7
	F2	5.5	2.3	928	275	185	0.0	0.0	0.8	1.2	1.7
	F7	18.9	29.0	9887	731	282	9.1	13.9	15.9	17.8	22.2
	F5	20.9	7.6	2697	676	353	2.0	3.9	4.4	5.1	5.6
	F3	50.4	14.6	3928	1579	936	7.7	10.5	11.4	12.4	14.0
Open	O8	0.1	7.3	618	713	0	0.0	0.0	1.3	0.4	7.3
	O7	14.1	3.2	36	895	403	0.0	1.3	2.1	3.2	3.2
	O3	16.2	1.2	297	222	0	0.0	0.3	0.8	1.2	1.2
	O6	16.4	2.5	305	345	0	0.0	0.1	1.3	2.5	2.5
	O5	42.2	4.7	301	797	318	0.0	0.7	2.1	4.0	4.7
	O1	72.7	14.3	1317	1660	602	0.0	4.4	10.1	12.8	13.9
	O4	122.9	20.5	2884	2089	739	0.9	7.0	9.8	12.6	20.5
	O2	230.1	16.6	961	1675	721	5.5	13.4	14.9	16.6	16.6

FC: farm contribution to the variation in maize carabid abundances – UAA-S: farm's area within the landscape unit – FI: length of fixed edge (one of the fields along the edge has a fixed land use in all simulations, eg. permanent grassland, wood or hedgerow) – VI: length of variable edges (both fields over the edge can have different covers according the years, eg. crops, temporary grasslands and lucerne) – VI-IN: variable edge length between two fields of the farm – Next 5 variables describes grassland area in the farm in all years simulated (min, average, max and 20/80 percentiles).

Table 3: Correlations of farm contribution to variation of maize carabid beetles with farm characteristics: only correlation with a p-value lower to 0.01 in one of the landscape unit are listed (D: dense landscape unit – O: Open landscape unit)

Variables	D		O	
	Spearman coefficient	P-value	Spearman coefficient	P-Value
VI	<b>0.93</b>	<b>0.002</b>	<i>ns</i>	<i>ns</i>
VI - IN	<b>0.94</b>	<b>0.001</b>	0.78	0.022
Average - p20	0.8	0.017	<b>0.85</b>	<b>0.008</b>
Average - mean	0.78	0.022	<b>0.84</b>	<b>0.001</b>
Average - p80	<i>ns</i>	<i>ns</i>	<b>0.92</b>	<b>0.001</b>

VI: length of variable edges (both fields over the edge can have different covers according to the years, eg.

crops, temporary grasslands and lucerne) – VI-IN: variable edge length between two fields of the farm –

Average p20 / mean / p80: average value of 20th percentile, mean and 80th percentile of grassland area