



1 *Classification:* BIOLOGICAL SCIENCES - Ecology

2
3 **Title: Increasing crop heterogeneity enhances multitrophic diversity across agricultural**
4 **regions**

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6 *Short title: Crop heterogeneity and multitrophic diversity*

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80 *Keywords:* multi-taxa, agricultural landscapes, crop mosaic, farmland, landscape
81 complementation

82 **ABSTRACT**

83 Agricultural landscape homogenization has detrimental effects on biodiversity and key
84 ecosystem services. Increasing agricultural landscape heterogeneity by increasing semi-
85 natural cover can help to mitigate biodiversity loss. However, the amount of semi-natural
86 cover is generally low and difficult to increase in many intensively-managed agricultural
87 landscapes. We hypothesized that increasing the heterogeneity of the crop mosaic itself
88 (hereafter “crop heterogeneity”) can also have positive effects on biodiversity. In eight
89 contrasting regions of Europe and North America, we selected 435 landscapes along
90 independent gradients of crop diversity and mean field size. Within each landscape, we
91 selected three sampling sites in one, two or three crop types. We sampled seven taxa (plants,
92 bees, butterflies, hoverflies, carabids, spiders, birds) and calculated a synthetic index of
93 multitrophic diversity at the landscape level. Increasing crop heterogeneity was more
94 beneficial for multitrophic diversity than increasing semi-natural cover. For instance, the
95 effect of decreasing mean field size from 5 to 2.8 ha was as strong as the effect of increasing
96 semi-natural cover from 0.5 to 11 %. Decreasing mean field size benefited multitrophic
97 diversity even in the absence of semi-natural vegetation between fields. Increasing the number
98 of crop types sampled had a positive effect on landscape-level multitrophic diversity.
99 However, the effect of increasing crop diversity in the landscape surrounding fields sampled
100 depended on the amount of semi-natural cover. Our study provides the first large-scale,
101 multitrophic, cross-regional evidence that increasing crop heterogeneity can be an effective
102 way to increase biodiversity in agricultural landscapes without taking land out of agricultural
103 production.

104

105 **SIGNIFICANCE STATEMENT**

106 Agricultural landscape homogenization is a major ongoing threat to biodiversity and the
107 delivery of key ecosystem services for human well-being. It is well known that increasing the
108 amount of semi-natural cover in agricultural landscapes has a positive effect on biodiversity.
109 However, little is known about the role of the crop mosaic itself. Crop heterogeneity in the
110 landscape had a much stronger effect on multitrophic diversity than the amount of semi-
111 natural cover in the landscape, across 435 agricultural landscapes located in eight European
112 and North American regions. Increasing crop heterogeneity can be an effective way to
113 mitigate the impacts of farming on biodiversity without taking land out of production.

114 INTRODUCTION

115 Agriculture dominates the world's terrestrial area (1, 2). Agricultural landscape
116 homogenization through the decrease of semi-natural cover, crop specialization and field
117 enlargement (3–6) represents a continuing worldwide threat to biodiversity and the delivery of
118 key ecosystem services to people (7, 8). There is ample evidence that enhancing landscape
119 heterogeneity by reversing the decline in semi-natural cover can benefit biodiversity in
120 agricultural landscapes (9–12). However, the amount of semi-natural cover keeps decreasing
121 in many agricultural landscapes, and the efficiency of policies focusing solely on maintaining
122 or increasing semi-natural cover has been questioned (13).

123 While half of the biodiversity in agricultural landscapes occurs exclusively in semi-
124 natural cover (14), the crop mosaic offers a wide range of resources to the other half,
125 including to species occurring exclusively in crop fields and providing key ecosystem
126 services, such as crop pollination or biological pest control (15–17). It is therefore of
127 increasing interest to evaluate whether enhancing landscape heterogeneity by increasing the
128 heterogeneity of the crop mosaic itself (hereafter “crop heterogeneity”) can also benefit
129 biodiversity (Fig. 1). There is growing pressure on agricultural land for food and energy
130 production as well as for urbanization. Therefore, measures to benefit biodiversity consisting
131 of a re-arrangement of the production area, as opposed to measures focusing solely on its
132 reduction, could provide valuable new sustainable policy options.

133 Crop heterogeneity can be decomposed into compositional heterogeneity, i.e. the
134 composition of the crop mosaic (e.g. crop diversity), and configurational heterogeneity, i.e.
135 the shape and spatial arrangement of fields (e.g. mean field size, 18; see further explanation in
136 *Methods*). These two components of crop heterogeneity may influence farmland biodiversity
137 in several ways (see detailed alternative hypotheses in SI 1). First, increasing crop diversity
138 may benefit biodiversity if many species are specialists of distinct crop types (i.e. habitat

139 specialization; **Hyp 1a** in **SI 1**; 19). In that case, sampling increasing numbers of crop types
140 should lead to observing increasing levels of species diversity. Second, increasing crop
141 diversity may also benefit biodiversity through a landscape-level effect if many species
142 require multiple resources provided by different crop types (i.e. landscape complementation;
143 **Hyp 1b** in **SI 1**; 20). In that case, sampling a given number of crop types surrounded by
144 increasing levels of crop diversity available in the landscape should lead to observing
145 increasing levels of species diversity. Third, decreasing mean field size may benefit
146 biodiversity through a landscape-level effect if small fields provide easier access to adjacent
147 crop fields for many species (i.e. landscape complementation; **Hyp 2a** in **SI 1**; 20, 21). In that
148 case, sampling a given number of fields surrounded by fields with decreasing mean sizes
149 should lead to observing increasing levels of species diversity.

150 Biodiversity responses to crop heterogeneity may be non-linear and non-additive. For
151 instance, increasing the diversity of crops available in the landscape may benefit biodiversity
152 in a given field only if fields are small enough for adjacent fields to be reached easily.
153 Additionally, the effects of increasing crop heterogeneity on biodiversity may depend on the
154 amount of semi-natural cover in the landscape. For instance, the ‘intermediate landscape-
155 complexity’ hypothesis (22) predicts that the positive biodiversity-crop heterogeneity
156 relationship is stronger in landscapes with intermediate amounts of semi-natural habitats (e.g.
157 5-20%) than in landscapes with little (e.g. <5%) or much semi-natural habitat (e.g. >20%; 10).
158 Sampling over a wide range of landscapes may therefore be necessary to understand the
159 general effect of crop heterogeneity on farmland biodiversity.

160 The biodiversity-crop heterogeneity relationship may vary among taxa (e.g. 23, 24).
161 For instance, it may be more positive for species and taxa that have lower habitat area
162 requirements (e.g. small species; 25) or higher habitat specialization levels (e.g. 26). Although
163 in-depth understanding of the effects of crop heterogeneity on each species or taxon is

164 valuable, it is also critical to develop environmental policies that are effective across a wide
165 range of species (27, 28). To achieve this, we here use a cross-regional sampling scheme in
166 Europe and North America and a synthetic index integrating information on multiple trophic
167 groups in order to identify landscape patterns that simultaneously increase the diversity of
168 most taxa (29).

169 We selected 435 landscapes along orthogonal gradients of mean size and diversity of
170 crop types available in the landscape in eight contrasting agricultural regions in France, the
171 United Kingdom, Germany, Spain and Canada (Fig. S2.1 in SI 2). In each landscape, we
172 selected three sampling sites in one, two or three crop types. We sampled seven taxa
173 representing a wide range of ecological traits, functions and trophic levels (plants, bees,
174 butterflies, hoverflies, carabids, spiders and birds) in each field. We then computed a synthetic
175 index of multitrophic diversity (*Methods*). We tested the relative effects of mean field size,
176 the number of crop types sampled, the diversity of crop types available in the landscape, and
177 the amount of semi-natural cover in the landscape on multitrophic diversity and on the species
178 richness of taxonomic groups. We also evaluated whether the effects of mean field size and
179 the diversity of crop types available in the landscape were non-linear, non-additive, and
180 influenced by semi-natural cover (see detailed hypotheses in SI 1).

181

182 **RESULTS AND DISCUSSION**

183 Our study provides the first large-scale evidence that crop heterogeneity is a major driver of
184 multitrophic diversity in agricultural landscapes. The number of crop types sampled in the
185 landscape, the mean size and diversity of crop types available in the landscape were
186 consistently included in all models (Fig. 2A). Together, they accounted for 61% of the
187 explained variance in multitrophic diversity, while semi-natural cover accounted for 24%
188 (Fig. 2B). Interactions between semi-natural cover and mean size/crop diversity of fields

189 available in the landscape also accounted for an important part of the explained variance
190 (15%), indicating that the effects of crop heterogeneity is modulated by the amount of semi-
191 natural cover in the landscape (Fig. 3). The effects of crop heterogeneity on multitrophic
192 diversity were consistent across the eight European and North American regions (Fig. 4). The
193 effects of crop heterogeneity on the species richness of taxonomic groups were similar to their
194 effects on multitrophic diversity and similar across the seven taxa (Fig. 5 and Fig. S5.2 in SI
195 5). They hold true when considering either landscape-level or field-level multitrophic
196 diversity, including when focusing only on cereal fields, the most dominant crop type across
197 our eight regions (Table S5.11 in SI 5). Their effects were also unchanged when potential
198 confounding factors such as the identity of crop types sampled, land-use intensity within
199 fields sampled (i.e. an index combining data on ploughing, fertilizer, herbicide and
200 insecticide), the composition of the crop mosaic, grassland cover or hedgerow length
201 available in the landscape were taken into account in our analyses (see additional analyses in
202 SI 5).

203

204 **Consistent positive effects of decreasing mean field size on multitrophic diversity**

205 Decreasing mean field size was the main driver of multitrophic diversity variations, mean
206 field size and mean field size² together accounting for 47.4% of the explained variance in
207 multitrophic diversity (Fig. 2B). The effect of decreasing mean field size from 5 to 2.75 ha
208 was as strong as the effect of increasing semi-natural cover from 0.5 to 11 % of the landscape
209 (Fig. 3B). Such a positive effect of decreasing mean field size on multitrophic diversity is
210 consistent with the hypothesis that smaller fields provide easier access to multiple cover
211 patches, in particular for species that require resources occurring in different cover types
212 (landscape complementation; 20, 21). The positive effect of decreasing mean field size was

213 particularly clear and strong when mean field size fell below 6 ha (93% of landscapes
214 studied).

215 Although the strength of this effect varied significantly among regions, decreasing
216 mean field size had a consistent positive effect across all regions studied (Fig. 4 and section
217 5.3 in SI 5). It was also consistently positive across all group of taxa considered separately,
218 from primary producers to predators (Fig. 5 and section 5.4 in SI 5). Previous studies have
219 already reported positive effects of decreasing mean field size on the diversity of several taxa
220 considered separately (30–34). Our study, based on multiple regions and multiple trophic
221 groups, shows that the benefits of decreasing mean field size can be generalized to
222 multitrophic diversity across a wide range of agricultural regions.

223 Previous studies suggested that the positive effect of decreasing mean field size on
224 multitrophic diversity may be primarily due to the presence of semi-natural vegetation
225 between fields (30–34). To test this hypothesis, we selected a subset of landscapes for which
226 mean field size and the length of semi-natural vegetation between fields were uncorrelated
227 (see details in section 5.5.3 in SI 5). The analysis, based on 274 landscapes, showed that the
228 positive effect of increasing mean field size on multitrophic diversity cannot be explained
229 solely by the increase in the length of semi-natural vegetation between fields. Increasing the
230 amount of semi-natural vegetation between fields had a positive effect on multitrophic
231 diversity but including this effect in our model did not change the effect of mean field size on
232 multitrophic diversity (Table S5.8 in SI 5). This result suggests that smaller fields benefit
233 multitrophic diversity even in the absence of semi-natural vegetation between fields.

234 Finally, the presence of the interaction term between mean field size and semi-natural
235 cover in our model (Fig. 2A) suggests that the effect of mean field size on multitrophic
236 diversity tends to be modulated by the amount of semi-natural cover available in the
237 landscape (Fig. 3B). To further explore this interaction, we used a moving window modeling

238 approach (35; see details in [section 5.7](#) in [SI 5](#)). This analysis confirmed that decreasing mean
239 field size had a consistent positive effect on multitrophic diversity along the gradient of semi-
240 natural cover. Moreover, it suggested that this effect is stronger when semi-natural cover is
241 below 8%, i.e. when semi-natural cover is too scarce to provide access to the multiple
242 resources required by most species occurring in agricultural landscapes ([Fig. S5.5.B](#) in [SI 5](#)).

243

244 **Complex effects of increasing crop diversity on multitrophic diversity**

245 The number of crop types sampled in each landscape and the diversity of crop types available
246 in the landscape surrounding sampled fields were consistently included in all models ([Fig.](#)
247 [2A](#)). This result suggests that both field-level (i.e. habitat specialization) and landscape-level
248 processes (i.e. landscape complementation and/or spill-over) can contribute to the effect of
249 crop diversity on multitrophic diversity (see further explanations in [SI 1](#) and [section 4.4.](#) in [SI](#)
250 [4](#)).

251 Increasing the number of crop types sampled had a significant positive effect
252 accounting for 13% of the explained variance in landscape-level multitrophic diversity ([Fig.](#)
253 [2B](#)). This result confirms that increasing crop diversity results in a larger number of distinct
254 habitats, and therefore higher biodiversity levels by increasing the number of specialist
255 species in the landscape ([Hyp 1a](#) in [SI 1](#), 26).

256 The main effect of increasing the diversity of crop types available in the landscape was
257 non-significant but the effect was significantly mediated by semi-natural cover. These effects
258 were consistent across all regions ([Fig. 4](#)). Together, the diversity of crop types available in
259 the landscape and its interaction with semi-natural cover accounted for 10% of the explained
260 variance in multitrophic diversity ([Fig. 2B](#)). The landscape-level effect of increasing crop
261 diversity on multitrophic diversity ranged from negative in landscapes with low semi-natural
262 cover to positive in landscapes with high semi-natural cover ([Fig. 3A](#)). This result is

263 consistent with the variability of effects observed across previous studies (30, 32, 34, 36, 37).
264 To further explore this interaction, we used the same moving window modeling approach
265 described above (see [section 5.7](#) in [SI 5](#) for details). This analysis confirmed that the
266 landscape-level effect of increasing crop diversity on multitrophic diversity was positive in
267 landscapes with more than 11% semi-natural cover (i.e. 50% of landscapes included in our
268 study), non-significant in landscapes with 4 to 11% semi-natural cover (i.e. 34% of
269 landscapes), and negative in landscapes with less than 4% semi-natural cover (i.e. 16% of
270 landscapes; [Fig. S5.5.A](#) in [SI 5](#)).

271 The positive landscape-level effect of increasing crop diversity on multitrophic
272 diversity observed in landscapes with more than 11% semi-natural cover supports the
273 ‘landscape complementation’ hypothesis ([Hyp 1b](#) in [SI 1](#)). This finding is consistent with the
274 fact that a diverse crop matrix provides a temporal continuity of food sources (38) while semi-
275 natural patches provide stable resources, for example, for nesting or shelter (e.g. 37). Such
276 complementation among multiple cover types has been described for several species (e.g. 38–
277 40). Our study, based on multiple regions and multiple trophic groups, shows that the positive
278 landscape-level effect of increasing crop diversity can be generalized to multitrophic diversity
279 across many agricultural landscapes (50% of landscapes included in our study).

280 The negative landscape-level effect of increasing crop diversity on multitrophic
281 diversity in landscapes with less than 4% semi-natural cover supports the ‘minimum total
282 habitat area requirement’ hypothesis ([Hyp 1c](#) in [SI 1](#)). This finding is consistent with the fact
283 that landscape simplification tends to filter out species with large body sizes (43), which also
284 have high minimum total habitat area requirements (44), and may therefore require high
285 amount of a single crop type. However, the whole range of taxa included in the present study,
286 associated with a wide range of ecological traits, and therefore a wide range of minimum total
287 habitat area requirements, showed a consistent response to crop diversity and the interaction

288 of crop diversity and semi-natural cover (Fig. 5). The ‘minimum total habitat area
289 requirement’ hypothesis therefore seems unlikely to solely explain our results. Other
290 hypotheses developed in the literature include the role of crop identity and management
291 practices (e.g. 41). We considered the possibility that, at low levels of semi-natural cover,
292 landscapes with higher crop diversity may have more intensive management practices, thus
293 reducing multitrophic diversity (as suggested in 34). For example, in Armorique and PVDS,
294 the increase in crop diversity was associated with a decrease in the cover of clover, a crop
295 type associated with extensive management practices, and an increase in the cover of
296 potatoes, a crop type associated with very intensive management practices (45). Reasons for
297 the negative landscape-level effect of increasing crop diversity on multitrophic diversity in
298 landscapes with low semi-natural cover deserve further attention. Future research is needed to
299 identify conditions under which increasing crop diversity leads to a consistent net positive
300 effect on multitrophic diversity, i.e. a positive effect of field-level (i.e. habitat specialization)
301 plus landscape-level (i.e. landscape complementation) processes.

302

303 **Implications for agricultural policies**

304 Our study has important implications for large-scale policy schemes implemented across a
305 wide range of contexts such as the European Common Agricultural Policy and its recent
306 greening (27), the Canadian Agriculture Policy Frameworks (46), or the United States Farm
307 Bill (47).

308 First, our results suggest that increasing crop heterogeneity may have a similar or
309 greater benefit for multitrophic diversity to increasing semi-natural cover (Fig. 2B) or even
310 decreasing field-level land use intensity (21; Table S5.12 in SI 5). Given current challenges to
311 increase semi-natural cover and limit chemical use in agricultural landscapes (48), policies
312 aiming at increasing crop heterogeneity may represent an effective and complementary way to

313 improve biodiversity conservation in agricultural landscapes. Policy measures favoring crop
314 heterogeneity may be more easily implemented than policies to increase semi-natural cover or
315 reduce chemical use (49). Associated with adequate economic incentives, they may also be
316 more favorably perceived by farmers and thus lead to higher uptake than measures requiring
317 farmers to take land out of production (48). Such measures may also contribute to the
318 development of new frameworks that reward farmers for sustainable land stewardship (50).

319 We observed a consistent effect of crop heterogeneity on species diversity across
320 seven taxa representing a wide range of ecological traits, functions and trophic levels (plants,
321 bees, butterflies, hoverflies, carabids, spiders and birds; Fig. 5). We observed landscapes
322 where six or even all seven taxa reached the threshold of 60% of the maximum species
323 richness observed within a given region (Fig. 4). Our study therefore suggests that policies to
324 increase crop heterogeneity would be an effective way to increase the diversity of all
325 components of biodiversity simultaneously and restore multitrophic biodiversity in
326 agricultural landscapes.

327 Finally, our results can contribute to the development of policies adapted to different
328 landscape contexts. For instance, our results suggest that policy measures aimed at decreasing
329 field sizes to below 6 ha may be particularly effective to promote multitrophic diversity in
330 agricultural landscapes, especially in landscapes where semi-natural cover is below 8%. Our
331 results also caution against a ‘blind’ increase of crop diversity. Measures aimed at increasing
332 crop diversity may be effective to promote multitrophic diversity in landscapes where semi-
333 natural cover exceeds 11%. However, they may have little effect or may even have negative
334 effects in intensive agricultural landscapes with little semi-natural cover. Our study therefore
335 highlights that measures promoting an increase in crop diversity are more likely to be
336 effective in promoting multitrophic diversity across all agricultural landscapes if combined
337 with measures promoting the restoration or maintenance of semi-natural cover.

338

339 **CONCLUSION**

340 Our study demonstrates the importance of crop heterogeneity for multitrophic diversity in
341 agricultural landscapes: the effect of maintaining/increasing crop heterogeneity is likely to be
342 as important as the effect of maintaining/increasing semi-natural cover. This finding suggests
343 that field enlargement and crop specialization, especially the former, have been
344 underestimated drivers of past and ongoing biodiversity declines. More importantly, our study
345 shows that increasing crop heterogeneity represents a major potential lever to increase
346 synergies between food production and biodiversity conservation.

347

348 **METHODS**

349 **1. Region, landscape and sampling site selection**

350 We selected eight agricultural regions (Armorique, Camargue, Coteaux de Gascogne
351 and Plaine et Val de Sèvre in France, East Anglia in the United Kingdom, Goettingen in
352 Germany, Lleida in Spain and Eastern Ontario in Canada; **Fig. S2.1 in SI 2**) belonging to six
353 different ecoregions (51) and differing in topography, climate, field shapes, and agricultural
354 cover types and products (e.g. rice, dairy, tree crops).

355 We used the best spatial data available within each region prior to field work to
356 identify all 1 km × 1 km rural landscapes, i.e. those dominated by agricultural cover (>60%,
357 including all crops and grassland managed for agricultural production). We then developed a
358 protocol to select a combination of landscapes that maximized the gradients of crop
359 compositional heterogeneity (crop diversity) and crop configurational heterogeneity (mean
360 field size) while minimizing the correlation between them (52). Crop diversity may
361 theoretically be constrained by the number and size of fields in landscapes with large fields.
362 However, in our dataset, mean field size was smaller than 12 ha and was therefore not a

363 limiting factor for crop diversity within the 1 km x 1 km landscapes. We selected between 32
364 and 93 landscapes within each region, totaling 435 landscapes across all regions.

365 We selected three sampling sites within each landscape, totaling 1305 sampling sites
366 across all regions. The number of crop types sampled ranged from one to three per landscape.
367 Where feasible, we located sampling sites in dominant agricultural cover types within each
368 region (e.g. wheat fields and oilseed rape in Goettingen). When this was not feasible, we
369 located sampling sites in agricultural cover types that were accessible within a given
370 landscape (SI 3). The three sampling sites were at least 200 m from each other, at least 50 m
371 from the border of the landscape, and at least 50 m from patches of non-agricultural cover
372 types such as forests and urban areas.

373

374 **2. Multi-taxa sampling**

375 We selected seven taxa representing a wide range of ecological traits, functions and
376 trophic levels which, combined into a multidiversity index (see below), represent a proxy for
377 multitrophic diversity: plants, bees, butterflies, hoverflies, carabids, spiders and birds. All taxa
378 were sampled using standardized sampling protocols across all regions, allowing us to test the
379 consistency of effects across the eight regions (Section 3.1 in SI 3).

380 At each sampling site, we selected two parallel 50 m ‘transects’, one located at the
381 field edge and the other inside the field 25 m away from the first transect (Fig. S3.1 and S3.2
382 in SI 3). Birds were sampled using point-counts centered on the field-edge transect. Plants
383 were surveyed along both transects. Butterflies were surveyed visually using timed walks
384 along both transects. Bees and hoverflies were sampled using colored pan traps on poles
385 erected at each end and in the center of all transects. Carabids and spiders were sampled using
386 pitfall traps installed at each end of all transects. Captured arthropods were preserved in
387 ethanol prior to identification. Multiple survey visits were conducted during the season when

388 relevant (SI 3). Each landscape was sampled during one year and sampling of landscapes was
389 distributed across two years within each region, between 2011 and 2014 (see further details on
390 the timing of our sampling in Table S3.1 in SI 3).

391 We identified more than 167,000 individuals from 2795 species (Table S3.2 in SI 3).
392 For each taxon, we calculated species richness at the landscape level, i.e. across all three
393 sampling sites and across all visits when multiple survey visits were conducted. The average
394 species richness per landscape varied greatly among taxa, from 5.4 for butterflies to 44.9 for
395 plants. Correlations in average species richness between pairs of taxa were weak (<0.41), with
396 an average correlation of 0.07 (Table S3.3 in SI 3).

397

398 **3. Multitrophic diversity index**

399 Our objective was to identify landscapes where the diversity of most taxa increases
400 simultaneously. A first approach used in the literature consists of calculating the average,
401 standardized diversity across taxa (53). However, this approach has limitations (see section
402 3.3 in SI 3). Although very high/low values imply that all taxa exhibit high/low diversity,
403 intermediate values are difficult to interpret as they may correspond to situations where (i)
404 diversity values are intermediate for all taxa, or (ii) diversity values are high for some taxa
405 and low for others, i.e. trade-offs among taxa.

406 To overcome this limitation, we used a threshold approach initially developed to
407 aggregate multiple ecosystem functions (29, 54). For each taxon and each region, we
408 identified the maximum species richness observed across all landscapes. We actually used the
409 95th percentile as the maximum observed species richness (hereafter ‘SR max’) in order to
410 minimize the effect of outliers. Next, we identified which landscapes attained a given
411 threshold (x) of SR max. We then tallied the proportion of taxa that exceeded the given

412 threshold in order to produce a multidiversity index (Tx.landscape) for each landscape, based
413 on the following formula:

$$414 \quad \text{Multidiversity (Tx. landscape)} = \frac{1}{n} \sum_{i=1}^{i=n} (\text{SR}_i > (x \times \text{SR max. region } j))$$

415 where n is the number of taxa for which data were available in a given landscape (see
416 details in [section 3.2 in SI 3](#)), SR_i is the number of species for taxon i, x is the minimum
417 threshold to be reached and $\text{SR}_{\text{max.region } j}$ is the maximum species richness for taxon i in the
418 region the landscape considered belonged to. This multidiversity index ranges between 0 and
419 1.

420 We calculated this multidiversity index for each threshold x between 20 and 90%
421 (every 10%). For each threshold x, the multidiversity index was smoothed by calculating the
422 average over the interval $[x - 10\%, x + 10\%]$ (55; see details in [section 3.3 in SI 3](#)).

423 Multidiversity indices calculated for different thresholds were strongly correlated. We chose
424 to use the intermediate threshold T60.landscape because 1) intermediate thresholds have been
425 shown to provide an effective measure of multitrophic diversity in agricultural landscapes
426 (53) and 2) T60.landscape shows a distribution ranging from 0, i.e. none of the taxa reach
427 60% of the regional maximum, to 100, i.e. all taxa reach 60% of the regional maximum (mean
428 value for T60.landscape = 45.1). Nevertheless, we verified that our results were not sensitive
429 to the threshold selected ([Fig. S5.2 in SI 5](#)). For simplicity, we hereafter refer to “landscape-
430 level multitrophic diversity” rather than T60.landscape.

431

432 **4. Crop compositional and configurational heterogeneity**

433 We used a standardized protocol across all regions to produce land cover maps
434 allowing us to compare consistency of effects across the eight regions ([SI 4](#)). We conducted
435 extensive ground-truthing surveys during the field seasons to map all fields, linear elements
436 between adjacent fields, and non-agricultural covers. We built a common land cover

437 classification for the eight regions. Agricultural cover types included all crops, as well as
438 temporary and permanent grassland managed for production purposes (SI 4). Linear elements
439 between fields included hedgerows, grassy margins, ditches and tracks. Non-agricultural
440 cover types included woodland (including woody linear elements), open land (e.g. extensive
441 grassland, shrubland, grassy linear elements), wetland and built-up areas (including roads).
442 We then used these standardized, detailed maps to calculate four explanatory variables for
443 each landscape: crop diversity, mean field size, semi-natural cover and total length of semi-
444 natural linear elements between fields.

445 We used the Shannon diversity of agricultural cover types (hereafter “crop diversity”;
446 CD) as a measure of crop compositional heterogeneity. We used mean field size in hectares
447 (MFS) as a measure of crop configurational heterogeneity. Neither CD nor MFS was
448 correlated with local land use intensity (an index combining data on ploughing, fertilizer,
449 herbicide and insecticide, see section 5.6.3 in SI 5) or the overall composition of the crop
450 mosaic (section 5.5.1 in SI 5) across all regions. CD and MFS were moderately correlated
451 with the type of crops sampled in some regions and MFS was moderately correlated with the
452 proportion of grassland in the crop mosaic, but none of these correlations affected our
453 conclusions (sections 5.5.1 and 5.5.2 in SI 5). We calculated the percentage of semi-natural
454 cover types, i.e. woodland, open land and wetland (SNC), in each landscape. We also
455 calculated the total length of linear semi-natural elements between fields, e.g. hedgerows,
456 grassy margins (SNL; measured in meters). SNL and MFS were highly correlated in some
457 regions (Table S5.6 in SI 5). As a result, we did not include SNL in the main analyses and
458 only tested the relative effect of MFS and SNL using a subset of our dataset for which MFS
459 and SNL were not strongly correlated (section 5.5.3 in SI 5).

460

461 **5. Data analysis**

462 We first tested the effect of crop heterogeneity on multitrophic diversity (Model 1).
463 We fitted a linear mixed model with Restricted Maximum Likelihood using the landscape-
464 level multidiversity index (T60.landscape) as the response variable. We included the number
465 of crop types sampled per landscape (CropNb), crop diversity (CD), mean field size (MFS)
466 and semi-natural cover (SNC) as explanatory variables (see alternative hypotheses on crop
467 heterogeneity-biodiversity relationships in SI 1). We included both interaction effects and
468 quadratic effects. Due to a positive skew in the distribution of mean field size, we used log
469 mean field size in all analyses. To reflect the large-scale spatial and temporal structure of our
470 dataset, we added sampling year (Year), nested within study region (Region), as a random
471 effect. To reflect the spatial structure of our dataset within each region, we included the
472 longitude and latitude of the center of each landscape (Lat, Lon) as covariates. We
473 standardized all fixed effects to allow for a direct comparison of estimates.

474

475 *Model 1: lmer (T60.landscape ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon + (1|*
476 *Region/Year))*

477

478 To test whether the effects of crop diversity, mean field size and semi-natural cover on
479 multitrophic diversity measured at the landscape level (T60.landscape) varied significantly
480 among regions we added random effects for region on the slopes of crop diversity, mean field
481 size, semi-natural cover as well as the interaction between crop diversity and semi-natural
482 cover (model 2). We assumed that the effects of region on the intercept and slopes were
483 uncorrelated. To test whether Region had a significant effect on the slope of either crop
484 diversity, mean field size, semi-natural cover as well as the interaction between crop diversity
485 and semi-natural cover, we used the function exactRLRT from package RLRsim.

486

487 *Model 2: lmer (T60.landscape ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon +*
488 *(1|Region/Year) + (0+CD|Region)) + (0+MFS|Region) + (0+SNC|Region) + (0+CD:SNC|Region))*

489

490 We then tested the effects of crop heterogeneity on the species richness of taxonomic
491 groups (Model 3). To do this, we fitted a similar model, using the landscape-level species
492 richness of taxonomic groups (SR) standardized within each taxon and region as the response
493 variable. To reflect that species pools vary between taxa, we added Taxon as a random effect.

494

495 *Model 3: lmer(SR ~ CD*MFS*SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon + (1|Region/Year) +*
496 *(1|Taxon))*

497

498 To test whether the effects of crop diversity, mean field size and semi-natural cover on
499 the species richness of taxonomic groups varied significantly among taxa we added random
500 effects for Taxon on the slopes of crop diversity, mean field size, semi-natural cover as well
501 as the interaction between crop diversity and semi-natural cover (model 4). We assumed that
502 the effects of Taxon on the intercept and slopes were uncorrelated. To test whether Taxon had
503 a significant effect on the slope of either crop diversity, mean field size, semi-natural cover or
504 the interaction between crop diversity and semi-natural cover, we used the function
505 exactRLRT from package RLRsim.

506

507 *Model 4: lmer(SR ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon + (1|Taxon) +*
508 *(1|Region/Year) + (0+CD|Taxon)) + (0+MFS|Taxon) + (0+SNC|Taxon) + (0+CD:SNC|Taxon))*

509

510 We fitted all models with the R lme4 package using LMER (56), we removed outliers
511 using function romr.fnc from package LMERConvenienceFunctions (57) and we ran
512 diagnostic tools to verify that residuals were independently and normally distributed, and
513 showed no spatial autocorrelation. For each model, a multimodel inference procedure was
514 applied using the R MuMIn package (58). This method allowed us to perform model selection
515 by creating a set of models with all possible combinations of the initial variables and sorting

516 them according to the Akaike Information Criterion (AIC) fitted with Maximum Likelihood
517 (59). We selected all models with $\Delta AIC < 2$ and used the model averaging approach using
518 LMER to estimate parameters and associated p-values, using the function `model.avg`. We ran
519 all analyses using the software R 3.4.0 (60).

520 We ran additional analyses to check that the composition of the crop mosaic, the
521 proportion of grassland in the crop mosaic, and the amount of semi-natural vegetation
522 occurring between fields did not affect our conclusions (section 5.5 in SI 5). We also ran
523 complementary analyses using field-level multidiversity (T60.field) as the response variable -
524 instead of the landscape-level multidiversity index (T60.landscape) - to check that our results
525 hold true at the field level, in particular within a subset of cereal fields, and that the type of
526 crop sampled or the level of land-use intensity within sampled fields did not affect our
527 conclusions (section 5.6 in SI 5). Finally, we used a moving window analysis to identify
528 potential discontinuities in multitrophic diversity response to crop diversity and mean field
529 size along the gradient of semi-natural cover (section 5.7 in SI 5).

530

531 **Acknowledgments**

532 This research was funded by the ERA-Net BiodivERsA, with the national funders French
533 National Research Agency (ANR-11-EBID-0004), German Ministry of Research and
534 Education, German Research Foundation and Spanish Ministry of Economy and
535 Competitiveness, part of the 2011 BiodivERsA call for research proposals. The UK
536 component of this research was funded by the UK Government Department of the
537 Environment, Food and Rural Affairs (Defra), as project WC1034. The Canadian component
538 of this research was funded by a Natural Sciences and Engineering Research Council of
539 Canada (NSERC) Strategic Project, the Canada Foundation for Innovation, Environment
540 Canada (EC), and Agriculture and Agri-Food Canada (AAFC). N.G. was supported by the
541 AgreeSkills+ fellowship programme which has received funding from the EU's Seventh
542 Framework Programme under grant agreement N° FP7-609398 (AgreeSkills+ contract). A.
543 G.-T. (Juan de la Cierva fellow, JCI-2012-12089) was funded by Ministerio de Economía y
544 Competitividad (Spain). C. Violle was supported by the European Research Council (ERC)
545 Starting Grant Project "Ecophysiological and biophysical constraints on domestication of crop
546 plants" (Grant ERC-StG-2014-639706-CONSTRAINTS). A.R.'s position at the University of
547 Alicante is funded by the 'Vicerrectorado de Investigación y Transferencia de Conocimiento'.
548 We would like to thank the hundreds of farmers and farm owners from all eight regions who
549 graciously permitted us to work on their lands. In addition to the co-authors, the project
550 involved direct assistance from more than 150 individuals for geomatics analyses, field

551 sampling, and species identification. We would like to thank all of them for their huge
552 contribution to the FarmLand project and this study. Finally, we are grateful to the GLEL
553 Friday Discussion Group for very helpful input.

554

555 **Author contribution**

556 CS and NG wrote the first draft of the manuscript; BP, FB, TT, VB, GS, AO, LB, JLM and LF
557 designed the FarmLand project; CS, ABB, CB, RC, AH, LH, PM, AA, JG, DG, G Bota, FC,
558 AGT, RG, SH, JR, XOSS, IR, JB, JAB, AR, MAM-G, JM and GS contributed data; CS, NG,
559 ABB, CB, RC, AH, LH, PM and AA analyzed data; all co-authors provided feedback on the
560 manuscript.

561

562

563

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- 704
- 705

706 **Figure legends**

707

708 **Figure 1.** A) Traditional representations of agricultural landscapes have focused on the
709 amount of semi-natural covers and semi-natural vegetation between fields, often considering
710 the farmed part of the landscape as a homogeneous matrix. These representations are
711 associated with the hypothesis that increasing the amount of semi-natural covers and semi-
712 natural vegetation between fields benefits biodiversity. B) Novel representations of
713 agricultural landscapes consider the heterogeneity of the crop mosaic. These representations
714 are associated with new hypotheses: increasing crop heterogeneity by increasing crop
715 diversity and/or decreasing mean field size, while maintaining semi-natural cover and semi-
716 natural vegetation between fields constant, benefits biodiversity (large squares represent
717 landscapes; adapted from 18).

718

719 **Figure 2.** Response of multitrophic diversity to the diversity of crop types available within the
720 landscape (CD), the number of crops sampled (Crop Nb), mean field size (MFS), semi-natural
721 cover (SNC), and interaction terms (CD:SNC, MFS:SNC, see further details in *Methods*),
722 based on data collected in 435 landscapes located in eight agricultural regions. Covariates
723 (Lon, Lat) were excluded from the figure for simplicity. A) Importance of each variable in the
724 model averaging approach (model 1), estimated as the proportion of submodels where the
725 variable was selected (see details in *SI 5*). B) The relative effect of each variable corresponds
726 to the ratio between its parameter estimate and the sum of all parameter estimates (i.e. the %
727 of variance explained, as explained in 60). Parameter estimates and confidence intervals,
728 based on a model averaging approach applied to model 1 (*Methods*). ° $p < 0.1$; * $p < 0.05$; **
729 $p < 0.01$; *** $p < 0.001$. Variables are grouped in three components: orange = crop
730 heterogeneity (MFS, MFS², CD, CD², MFS:CD, Crop Nb), green = semi-natural cover (SNC,
731 SNC²), blue = interactive effects between crop heterogeneity and semi-natural cover
732 (CD:SNC, MFS:SNC, CD:MFS:SNC). The % of variance explained by CD is too small to be
733 visible.

734

735 **Figure 3.** Effect of the diversity of crop types available within the landscape (CD), mean field
736 size (MFS), semi-natural cover (SNC), and their interaction terms on landscape-level
737 multitrophic diversity (see further details in *Methods*), based on data collected in 435
738 landscapes located in eight agricultural regions. A) Interactive effects of crop diversity and
739 semi-natural cover on multitrophic diversity. B) Interactive effects of mean field size and
740 semi-natural cover on multitrophic diversity. The direction of the mean field size axis is
741 reversed to improve readability. The parameter estimates of all other variables were fixed to
742 their mean values, i.e. zero, as all predictors were scaled. Black dots and surfaces correspond
743 to values of multitrophic diversity predicted by the model averaging approach applied to
744 model 1 (*Methods*). The color gradient corresponds to multitrophic diversity values, ranging
745 from low values (blue) to high values (red). Grey dots show the overall gradients of crop
746 diversity, mean field size and semi-natural cover across the 435 landscapes located in eight
747 regions.

748

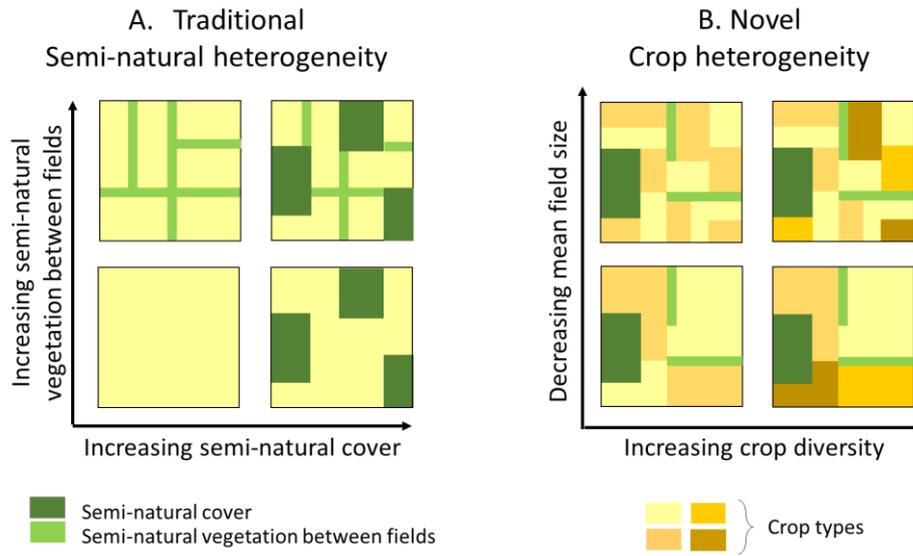
749 **Figure 4.** Effects of the diversity of crop types available in the landscape (CD), mean field
750 size (MFS), semi-natural cover (SNC) and the interaction between crop diversity and semi-
751 natural cover (CD:SNC) on multitrophic diversity in different regions (see further details in
752 *Methods*). Slopes are based on the outputs of model 2 including a random effect of region on
753 these four slopes (n=435 landscapes). Colors indicate the region.

754

755 **Figure 5.** Effects of the diversity of crop types available in the landscape (CD), mean field
756 size (log MFS), semi-natural cover (SNC) and the interaction between the diversity of crop
757 types available in the landscape and semi-natural cover (CD:SNC) on the landscape-level
758 species richness of taxonomic groups (see further details in *Methods*). Slopes are based on the
759 outputs of model 10 including a random effect of taxon on these four slopes (n=435
760 landscapes). Colors indicate the taxon.
761

762 **Figure 1.**
763

Representations of farmland heterogeneity

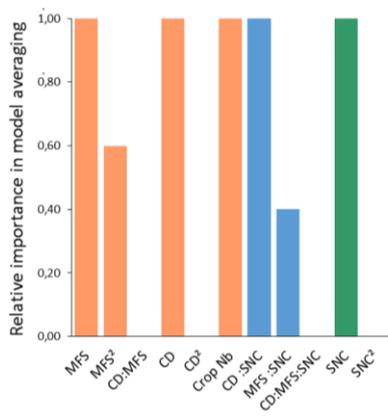


764

765 **Figure 2**

766

767 **A**



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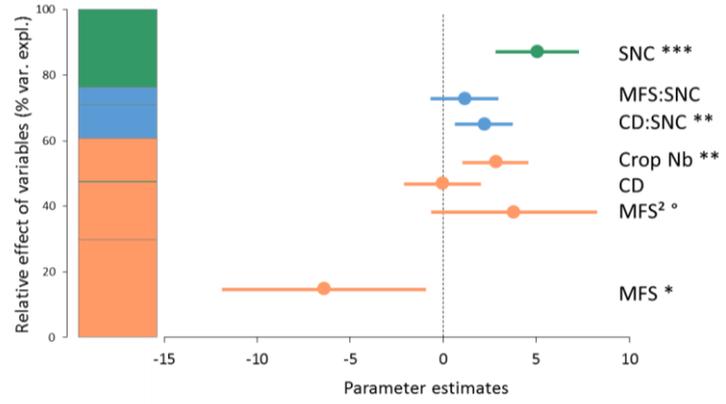
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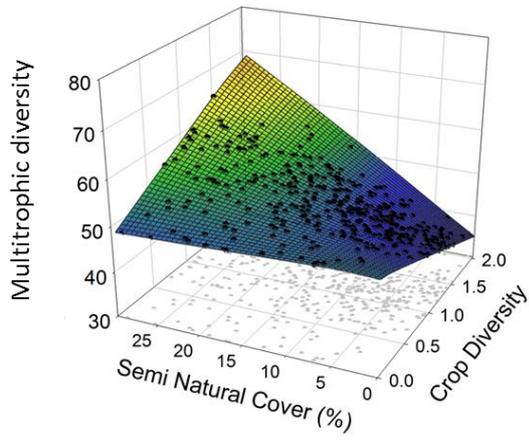
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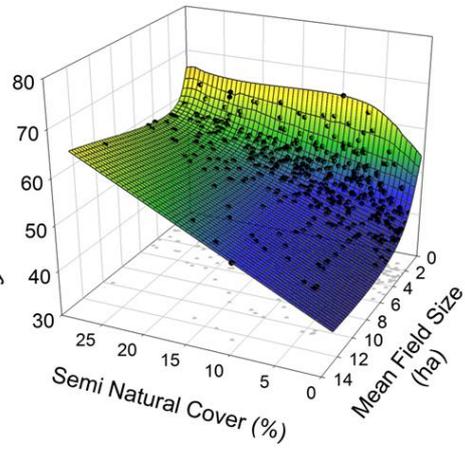


773 **Figure 3.**

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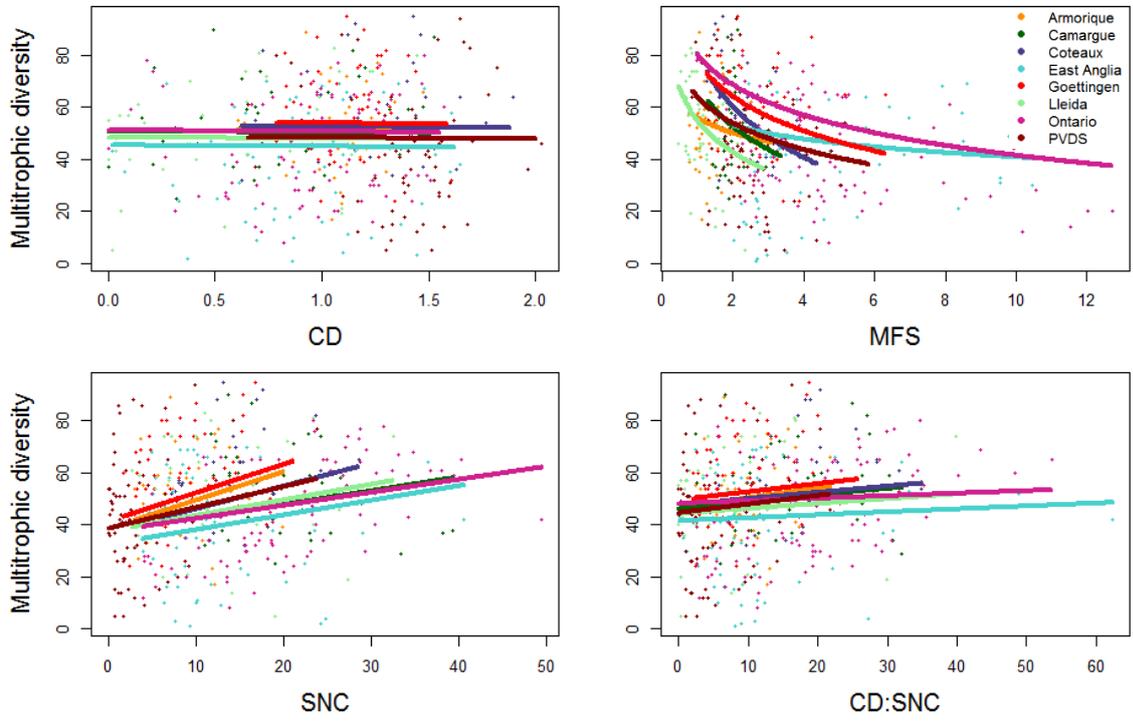


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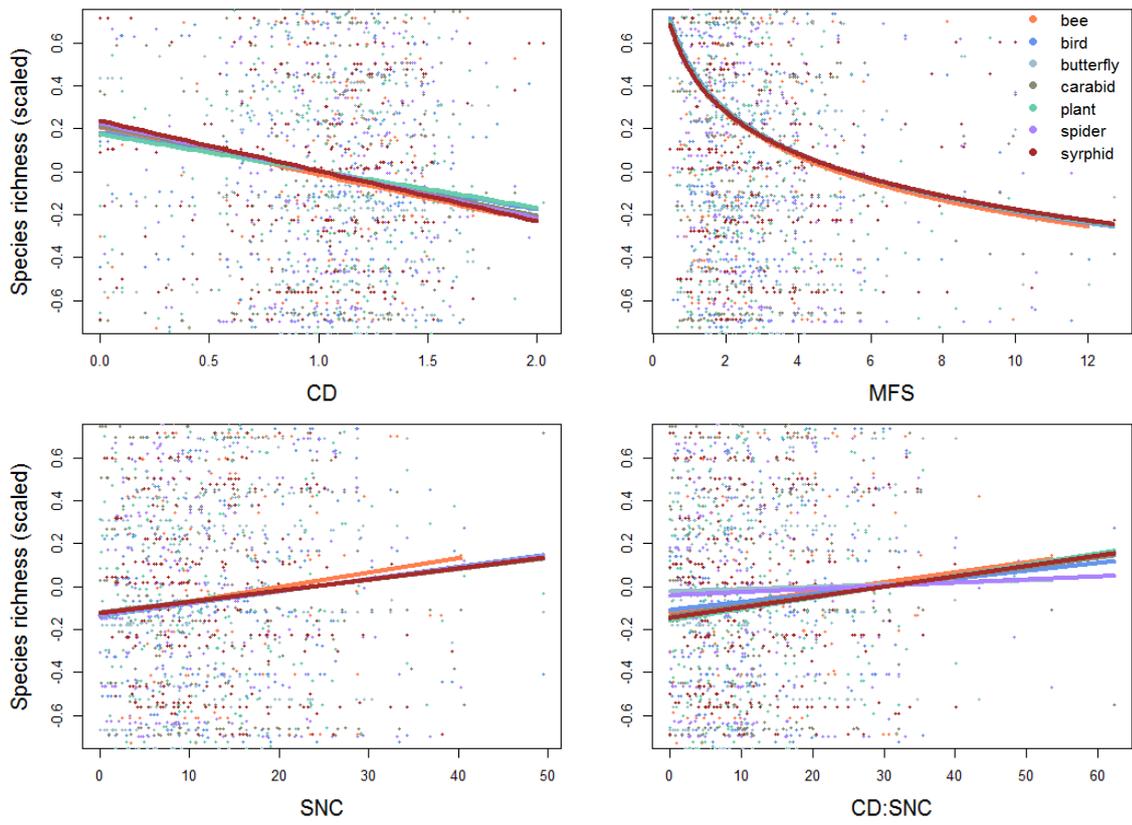
777 **Figure 4.**

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781 **Figure 5.**



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787 **Supporting Information**

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789 SI 1 – Hypotheses on the effects of crop heterogeneity on biodiversity

790 SI 2 – Region and landscape selection

791 SI 3 – Multitrophic diversity sampling

792 SI 4 – Land cover mapping and landscape metrics

793 SI 5 – Complementary analyses

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795 **SI 1 – Hypotheses on the effects of crop heterogeneity on biodiversity**

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798 **1.1. Crop compositional heterogeneity (increasing crop diversity)**

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800 **Hyp 1a.** Biodiversity **increases** with increasing crop diversity if different crop types can serve as
801 habitat for different specialized species (single habitat specialization; Andreasen et al. 1991; Weibull
802 et al. 2003). In that case, sampling more crop types will result in observing higher landscape-level
803 biodiversity.

804

805 **Hyp 1b.** Biodiversity **increases** with increasing crop diversity if different crop types provide different
806 resources required for single species (landscape complementation; Dunning et al. 1992), or if
807 specialist species spillover from other crop types in the landscape into the fields sampled (Duelli
808 1997, Schneider et al. 2016). In that case, for a given number of crop types sampled, landscapes with
809 higher crop diversity will result in observing higher landscape-level biodiversity.

810

811 **Hyp 1c.** Biodiversity **decreases** with crop diversity if most species have high minimum total habitat
812 area requirements, i.e. require large amounts of a single crop type. An increase in the number of
813 crop types available in the landscape results in a decrease in the total area of each crop type
814 available in the landscape, which could hypothetically result in insufficient resources for species
815 associated with individual crop types (Fahrig et al. 2011; Tscharntke et al. 2012).

816

817 **Hyp 1d.** Biodiversity shows a **peaked relationship** with crop diversity available in the landscape
818 (Allouche et al. 2012) if there is an initial increase in biodiversity with increasing crop diversity for
819 reasons explained in Hyp 1a-1b, but at higher levels of crop diversity, each crop type has a lower
820 spatial cover and biodiversity decreases for reasons explained in Hyp 1c.

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823 **1.2. Crop configurational heterogeneity (decreasing mean field size)**

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825 **Hyp 2a.** Biodiversity **increases** with decreasing mean field size if landscapes with smaller fields
826 provide easier access to multiple fields for species that require resources occurring in different crop
827 types (landscape complementation).

828

829 **Hyp 2b.** Biodiversity **increases** with decreasing mean field size if landscapes with smaller fields also
830 have higher density of crop edges. This could increase biodiversity measured in sampled crop fields
831 by increasing spillover from adjacent fields or from adjacent semi-natural vegetation occurring
832 between fields.

833

834 **Hyp 2c.** Biodiversity **decreases** with decreasing mean field size if most species show negative edge
835 effects and/or if most species have minimum patch size requirements (separate from their total
836 habitat area requirements, see Hyp1c).

837

838 **Hyp 2d.** Biodiversity shows a **peaked relationship** with decreasing mean field size if there is an initial
839 increase in biodiversity for reasons explained in Hyp 2a-2b and then biodiversity decreases when
840 mean field size reaches minimum patch size requirements for most species (Hyp 2c).

841

842

843 **1.3. Interactions between crop compositional and configurational heterogeneity**

844

845 **Hyp 3a.** The positive effect of crop diversity on biodiversity is **stronger** when mean field size
846 decreases (and vice-versa) if most species require multiple land cover types easily accessible
847 (landscape complementation). This is because increasing crop diversity increases the chance that all
848 required crop types are available, and decreasing field sizes increases accessibility among the
849 required crop types.

850
851 **Hyp 3b.** The positive effect of crop diversity on biodiversity is **weaker** when mean field size is low if
852 most species require landscape complementation and have minimum patch size requirements.
853 Similarly, the positive effect of decreasing mean field size on biodiversity is **weaker** when crop
854 diversity is high if the presence of a distinct crop type in the adjacent field results in a negative edge
855 effect for most species within the sampled field.

856
857 **Hyp 3c.** The positive effect of crop diversity on biodiversity is **independent** of mean field size if most
858 species are highly mobile and can access multiple fields regardless of mean field size. The positive
859 effect of decreasing mean field size on biodiversity is **independent** of crop diversity if most species in
860 landscapes with low mean field size primarily benefit from an easier access to semi-natural cover, in
861 particular to semi-natural linear elements, rather than to multiple fields.

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864 **1.4. Interactions between crop heterogeneity and semi-natural cover**

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866 **Hyp 4a.** The positive effect of **crop diversity** on biodiversity is **stronger** when semi-natural cover
867 (SNC) increases if most species require complementary resources found in semi-natural cover types
868 and several crop types (e.g. species require SNC + crop A + crop B).

869

870 **Hyp 4b.** The positive effect of decreasing **mean field size** on biodiversity is **stronger** when semi-
871 natural cover (SNC) increases if most species in landscapes with low mean field size primarily benefit
872 from an easier access to semi-natural cover, in particular to semi-natural linear elements, rather than
873 an easier access to multiple fields.

874

875 **Hyp 4c.** The positive effects of crop heterogeneity on biodiversity is stronger in landscapes with
876 **intermediate amounts of semi-natural cover** than in landscapes with very low or very high semi-
877 natural cover (Tscharrntke et al. 2012). In landscapes with no or very low semi-natural cover, species
878 pool may be small and species may be well adapted to intensive agriculture, and biodiversity may
879 therefore remain unaffected by crop heterogeneity levels. In landscapes with high semi-natural
880 cover, biodiversity levels may be high everywhere due to widespread spill-over effects, and may
881 remain unaffected by crop heterogeneity levels.

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885

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901 **SI 2 – Region and landscape selection**

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903

904 **2.1. Region selection**

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906 We selected eight agricultural regions (Fig. S2.1) that belong to six different ecoregions (Olson et al;
907 2001)(51) : Eastern Great Lakes lowland forests (Eastern Ontario in Canada), Celtic broadleaf forests
908 and English lowland beech forests (East Anglia in United Kingdom), Atlantic mixed forests
909 (Armorique, Plaine et Val de Sèvre in France), Western European broadleaf forests (Goettingen in
910 Germany, Coteaux de Gascogne in France), Iberian sclerophyllous and semi-deciduous forests (Lleida
911 in Spain) and Northeastern Spain & Southern France Mediterranean forests (Camargue in France).
912 Topography varied from flat (e.g. Camargue, Eastern Ontario) to intermediate (e.g. Goettingen,
913 Lleida), to hilly (e.g. Coteaux de Gascogne). Climate varied from dry (e.g. Lleida) to humid (e.g. East
914 Anglia). Complexity in crop field shapes varied from rectilinear (e.g. Camargue, Eastern Ontario) to
915 intermediate complexity (e.g. Coteaux de Gascogne, Armorique) to complex field shapes (e.g. Lleida).
916 Specific agricultural products were found in some regions, e.g. dairy (Armorique), olives (Lleida) or
917 rice (Camargue). Diversity of agricultural cover types varied from low (e.g. Camargue, Lleida) to high
918 (e.g. Coteaux de Gascogne, Plaine et Val de Sèvre). Mean field size varied from 1.2 ha in Lleida and
919 1.4 ha in Armorique to 4.4 ha in Eastern Ontario and 4.7 ha in East Anglia.

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922 **Figure S2.1.** Locations of the eight study regions in Europe and North America.

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924

925 **2.2. Landscape selection**

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927 The purpose of the landscape selection protocol was to select in each region a set of landscapes
928 in a pseudo-experimental design (also called a "mensurative experiment") which aimed at selecting
929 agricultural landscapes (between 60 and 100% of agricultural cover) along two independent
930 gradients of crop compositional and configurational heterogeneity. The general protocol is detailed
931 in Pasher et al. (2013).

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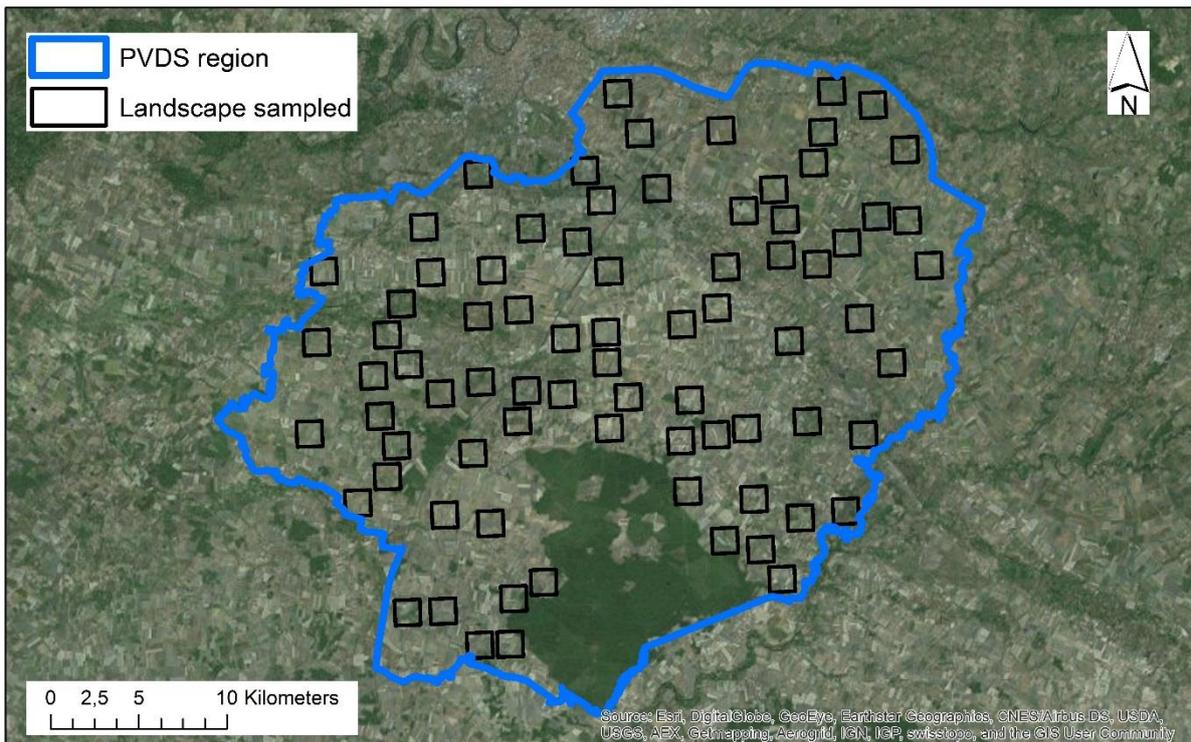
933 We used the highest resolution and most recent remotely sensed data or the best land cover
934 map available within each region. We delineated all fields (contiguous production cover), even when
935 adjacent fields contain the same agricultural cover type (as they may belong to different farmers or
may be managed differently). We attributed each field to one of the following 34 agricultural cover

936 types: cereal, fallow, alfalfa, clover, ryegrass, grassland, rice, corn, sunflower, sorghum, millet, moha,
937 oilseed rape, mustard, pea, bean, soybean, linseed, orchard, almond, olive, vineyard, mixed
938 vegetables, sugar beet, asparagus, carrot, onion, parsnip, potato, tomato, melon, strawberry,
939 raspberry, wild bird cover (i.e. a spring sown crop left unharvested over winter to provide food for
940 farmland birds). We also delineated patches of non-agricultural cover (woodland, open land, wetland
941 and built-area).

942 We then calculated crop compositional heterogeneity (Shannon diversity index of the crop
943 mosaic) and crop configurational heterogeneity (mean size of agricultural fields) as well as
944 agricultural cover.

945 We selected spatially independent agricultural landscapes (between 60 and 100% of agricultural
946 cover) within each region (Fig. S2.2), representing the maximum variation for both crop
947 compositional heterogeneity and crop configurational heterogeneity.

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950 **Figure S2.2.** Spatial distribution of landscapes sampled in one of the eight regions (PVDS = Plaine et Val
951 de Sèvre).
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964 383.

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967 **SI 3 – Multitrophic diversity sampling**

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970 **3.1. Sampling site selection**

971 Disentangling the effects of crop diversity and mean field size on multitrophic diversity required
972 sampling many landscapes. Trade-offs between the number of landscapes sampled and the number
973 of sampling sites per landscape were unavoidable. Whereas studies assessing the effect of landscape
974 structure on biodiversity are often based on a single sampling site per landscape, we decided to
975 sample three sampling sites (i.e. three agricultural fields) within each landscape of 1 x 1 km (Fig.
976 S3.1). These sites were located at least 200 m apart from each other, at least 50 m from the border
977 of the 1km x 1km landscape, and at least 50 m from non-agricultural cover such as forests.

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We sampled either one, two or three distinct crop types per landscape. We located these sampling sites in dominant crop types within each region. When this was not feasible, we located sampling sites in crop types available within a given landscape while limiting correlations between crop types sampled and the two heterogeneity gradients within each region (see further details in SI 5).

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At each sampling site, we selected two parallel 50 m ‘transects’, one located at the field edge and the other inside the field 25 m away from the first transect (Fig. S3.2).



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Figure S3.1. Example landscape showing the three selected sampling sites.

990 **3.2. Multitrophic diversity sampling within each sampling site**

991 Multitrophic diversity sampling occurred between 2011 and 2014 depending on the region and
992 landscape (Table S3.1).

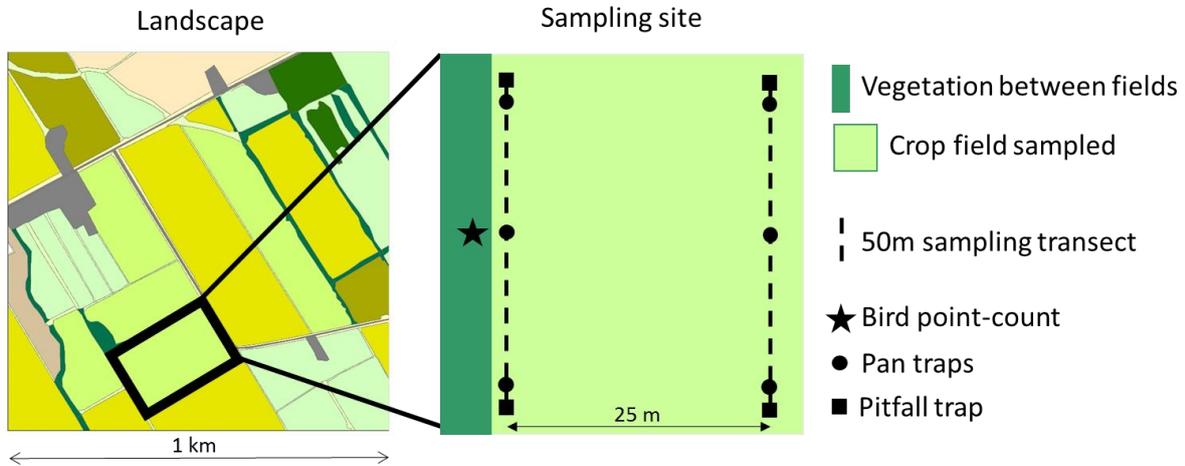
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Table S3.1. Number of landscapes sampled and main crop types sampled within each region and each year.

Region	2011	2012	2013	2014	Total	Crop types sampled
Armorique			30	10	40	cereal, corn, grassland
Camargue			32	8	40	rice, cereal
Coteaux			20	12	32	cereal, corn, sunflower
East Anglia		30	30		60	cereal, sugar beet, oilseed rape
Goettingen			32	20	52	cereal, oilseed rape, grassland
Lleida			25	15	40	cereal, almond, olive
Eastern Ontario	46	47			93	corn, soybean, grassland

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All taxa were sampled using sampling methods commonly used in the literature (point counts, traps, visual surveys; Fig. S3.2; Fahrig et al. 2015).



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Figure S3.2. Multitrophic diversity sampling design within each sampling site within each landscape (1 km x 1 km).

While trade-offs between the number of sites sampled and sampling intensity at each site were necessary, our sampling efforts (see below: number of traps, length of transects, number of visits) were consistent with the literature (e.g. Pollard and Yates 1993, Bibby et al. 2005, Geiger et al. 2010). **Table S3.2** shows the number of species and specimens we sampled for each taxa.

Table S3.2. Number of species and specimens (occurrences for plants) for each taxa.

	Species	Specimens
All taxa	2795	167028
Bees	343	13326
Birds	208	10911
Butterflies	109	10605
Carabids	256	42547
Hoverflies	146	21491
Plants	1229	30276
Spiders	504	37872

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Plants - Plant surveys were conducted along the field edge and in the field interior transects. Percentage cover was recorded for each species. Each transect was 1 m wide and 50 m long and represented a total surveyed area of 20 m², except in Eastern Ontario where plant survey transects were 2m wide, represented a total surveyed area of 100 m² and the field edge transect included both the field and the boundary vegetation. Plant surveys were conducted once, except in Eastern Ontario, Goettingen and East Anglia where surveys were conducted twice.

Bees and hoverflies – Bees and hoverflies were sampled using colored pan traps, except for hoverflies in Eastern Ontario which were sampled by sweep-netting along the two transects. Plastic bowls painted in UV blue, white or UV yellow were placed in pairs at each end and at the center of each transect. As a result, we used six pan traps per transect, 12 pan traps per sampling site and 36 pan traps per landscape. The height of pan traps was adjusted to vegetation height. Cups were filled with water, with three drops of odorless soap added per 1L of water. The traps were left in the field for four days. The insects were then stored in 70 % ethanol and later identified to species level. Bee and hoverfly sampling was carried out twice during the growing season (April-July), the dates being

1025 selected in each region based on regional climatic conditions. Therefore rarefied species richness
1026 could not be calculated. Due to technical and financial constraints, bees could only be identified to
1027 species level in seven of the eight regions, and in a total of 183 landscapes. This did not affect our
1028 results (see section 3.3 of this SI).

1029
1030 **Carabids and spiders** - Carabids and spiders were sampled using pitfall traps (Bertrand et al. 2016).
1031 Cups were half-filled with a solution of 10 drops of soap and 10 g of salt per 1L of water and placed in
1032 the ground. One trap was placed at each end of each transect (two traps per transect and four per
1033 sampling site in total). The traps were left in the field for four days. Arthropods were then stored in
1034 70 % ethanol and carabids and adult spiders were later identified to species level. Carabids and
1035 spiders were sampled at the same time as the bee and hoverfly sampling (above). They were carried
1036 out only once in East Anglia in 2012 due to bad weather conditions and could not be conducted in
1037 rice fields in Camargue due to the presence of water.

1038
1039 **Butterflies** - Butterfly surveys were conducted along the field edge and in the field interior transects
1040 (Pollard and Yates 1993). Surveys were conducted on calm (Beaufort scale < 3), sunny days, when the
1041 temperature was > 15°C. The observer recorded all butterfly species observed within an imaginary 5
1042 m-sided box (2.5 m to each side, 5 m in front and 5 m high) during approximately 10 min per transect
1043 (Pollard and Yates 1993). Individuals that could not be identified by sight were captured with a
1044 butterfly net for closer examination (survey time was stopped during capture and identification).
1045 Surveys were conducted once, except in Eastern Ontario, Goettingen and Lleida where surveys were
1046 conducted twice.

1047
1048 **Birds** - Birds were surveyed using 10-minutes point counts (Bibby et al. 2005) located at the center of
1049 the border transect. All individuals singing or seen within a distance of 100m were recorded. Birds
1050 flying across were considered as transients and thus not included. Counts were conducted twice,
1051 except in East Anglia in 2012 due to bad weather conditions, in Ontario and in rice fields in Camargue
1052 due to the specific phenology of this crop type, where they were conducted once. Surveys were
1053 conducted during the peak breeding season, between April and June depending on the region, and
1054 during peak activity hours, from 1 to 4 hours after sunrise and under good weather conditions.

1055
1056 **Note on detection and rare species** – Our sampling scheme presents the following characteristics : 1)
1057 the three fields within each landscape often correspond to different crop types and therefore
1058 correspond to different species pools; 2) we only sampled each landscape during a single year; 3) we
1059 sampled some taxa across two sessions within the sampling season but these sessions target distinct
1060 communities (e.g. spring versus summer spider communities); 4) some protocols involve multiple
1061 sampling within the field (e.g. several pitfall traps along the edge transect and several pitfall traps
1062 along the center transect) but these traps cannot be considered as replicates due to the high level of
1063 heterogeneity within fields, both between transects and within a transect. As a result, we do not
1064 think we have truly replicated data that would allow us computing species richness estimators such
1065 as the Chao estimator. Nevertheless, because we used standard protocols commonly used in the
1066 literature, we believe that when pooling the data at the landscape level, our uncorrected data is a
1067 good proxy of species richness for each taxa studied.

1068 1069 **3.3. Multidiversity**

1070 An important challenge when studying the overall effects of crop heterogeneity on multitrophic
1071 diversity is that different taxa might respond differently (Flynn et al. 2009; Kormann et al. 2015;
1072 Concepción 2016). Indeed, we observed weak correlations among taxa within our dataset (Table
1073 S3.3) and significant differences in the response of taxa (Fig. 4 in the main text).

1074
1075 **Table S3.3.** Mean species richness per landscape \pm standard deviation for each taxa and correlations among
1076 taxa (Pearson correlation coefficients). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

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	Mean SR	birds	bees	butterflies	carabids	hoverflies	plants
birds	18.7±6.7						
bees	11.2±4.6	0.11					
butterflies	5.4±2.9	0.03	0.14				
carabids	12.3±6.8	0.01	-0.18*	0.13**			
hoverflies	6.4±3.7	-0.04	0.14	0.09	0.25		
plants	44.9±17.5	0.19	-0.07	0.23	-0.21	0.12	
spiders	20.6±11.5	0.17*	0.41***	-0.20**	0.34***	0.16***	-0.27

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To test the overall effects of crop heterogeneity on multitrophic diversity, we investigated methods developed by Allan et al. (2014) to study ecosystem multifunctionality. Such approach differs from testing how crop heterogeneity impacts each taxa separately by searching for optimal landscape conditions that promote most taxa simultaneously.

A first approach to achieve this is to calculate a multidiversity index based on the averaged approach (Byrnes et al. 2014). This approach consists simply in calculating the average standardized values of multiple taxonomic diversities for each landscape, as follows:

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$$\text{Average-based Multidiversity} = \frac{1}{7} \times \sum_{i=1}^{n=7} \text{scale}(SR_i, \text{center}=T, \text{scale}=T)$$

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where SR_i is the number of species for taxa i in a given landscape.

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Although this averaging approach provides an intuitive method to assess changes in diversity across multiple taxa simultaneously (Allan et al. 2014), the averaged-approach includes some biases. For instance, very high averaged-multidiversity values implies that all groups exhibit high diversity. However, intermediate averaged-multidiversity values are difficult to interpret and it is impossible to differentiate situations where (i) diversity values are intermediate for all taxa simultaneously; or (ii) diversity values are very high for some groups while they are very low for others, i.e. trade-offs among taxa (Byrnes et al. 2014).

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To overcome this limitation, we used a threshold approach (Zavaleta et al. 2010) not biased by potential trade-offs among taxa (Byrnes et al. 2014). The objective of this approach is to assess the ability of agricultural landscapes to simultaneously host at least a given percentage, or threshold (x), of the maximum species richness observed for each taxa (SR_{max}). Because SR_{max} is likely to vary between regions, we chose to use the 95th percentile of the maximum observed species richness within each region as $SR_{max,region}$ for each taxa. We then calculated the multidiversity index based on the following formula:

1105

$$\text{Threshold – based Multidiversity (Tx.landscape)} = \frac{1}{7} \sum_{i=1}^{n=7} (SR_i > (x \times SR_{max,region j}))$$

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where SR_i is the number of species for taxa i , x is the minimum % to reach and $SR_{max,region}$ is the maximum species richness for group i in the region the landscape considered belong to. For a given taxon, if SR_i is above the threshold, this taxon is associated with the value 1. The sum ranges between 0 and 7, and the multidiversity index ranges between 0 and 1.

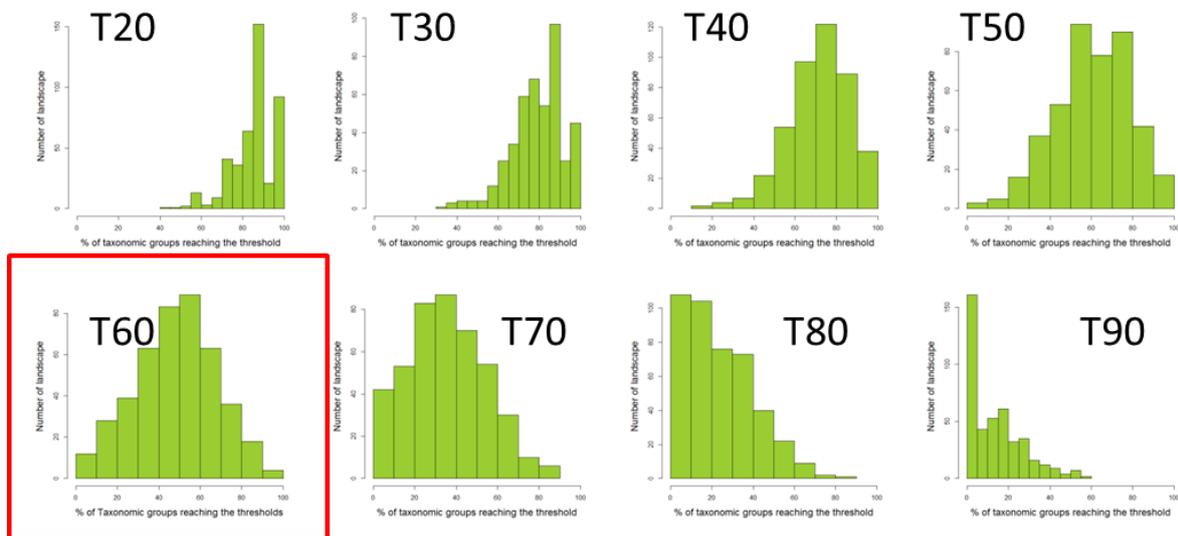
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We calculated this multidiversity index for each threshold x between 20 and 90% (every 10%). For each threshold x , the multidiversity index was smoothed by calculating the average over the interval $[x - 10\%, x + 10\%]$ (Le Bagousse-Pinguet et al. 2019). It is recommended to focus on intermediate

1114 thresholds since care should be taken to avoid over-interpreting high or low thresholds (Lefcheck et
 1115 al. 2015) and intermediate thresholds have been shown to provide an effective measure of
 1116 multitrophic diversity in agricultural landscapes (Byrnes et al. 2014). We chose to focus our analyses
 1117 on the threshold of 60% after checking that the distribution of T60.landscape allows developing
 1118 robust linear statistics (Fig.S3.3).
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1120
 1121 **Figure S3.3.** Distribution of the threshold-based multitrophic diversity calculated at the landscape
 1122 level for thresholds between 20 and 90%.

1123
 1124 A high multidiversity value based on a threshold of 60% means that most taxa are associated
 1125 with species richness levels higher than 60% of the regional maximum (SRmax.region) observed in
 1126 our study. Note that (i) T60.landscape was highly correlated with the averaged multidiversity index in
 1127 our dataset and other threshold-based multidiversity indices (Table S3.4) (ii) our results were not
 1128 sensitive to the threshold selected (Fig. S5.1 in SI 5).
 1129

1130 **Table S3.4.** Correlation between average-based multidiversity (M), various threshold-based
 1131 multidiversity indices calculated at the landscape level (T) and species richness for each taxa. Colors
 1132 correspond to increasing correlation values (from orange to dark red).
 1133

	M	T20	T30	T40	T50	T60	T70	T80	Plant	Bee	Syrphid	Butterfly	Carabid	Spider	Bird
M	1	0.48	0.60	0.71	0.80	0.86	0.88	0.86	0.51	0.59	0.39	0.54	0.56	0.64	0.37
T20	0.48	1	0.92	0.77	0.65	0.58	0.52	0.47	0.08	0.19	0.23	0.21	0.07	0.22	0.61
T30	0.60	0.92	1	0.93	0.79	0.69	0.62	0.56	0.15	0.31	0.23	0.28	0.21	0.31	0.59
T40	0.71	0.77	0.93	1	0.93	0.82	0.74	0.66	0.23	0.45	0.27	0.34	0.33	0.40	0.54
T50	0.80	0.65	0.79	0.93	1	0.94	0.85	0.74	0.32	0.54	0.28	0.39	0.41	0.48	0.50
T60	0.86	0.58	0.69	0.82	0.94	1	0.95	0.84	0.38	0.57	0.28	0.44	0.45	0.54	0.46
T70	0.88	0.52	0.62	0.74	0.85	0.95	1	0.95	0.42	0.54	0.29	0.45	0.46	0.59	0.43
T80	0.86	0.47	0.56	0.66	0.74	0.84	0.95	1	0.42	0.48	0.29	0.43	0.45	0.57	0.44
Plant	0.51	0.08	0.15	0.23	0.32	0.38	0.42	0.42	1	0.04	0.01	0.22	0.21	0.18	0.00
Bee	0.59	0.19	0.31	0.45	0.54	0.57	0.54	0.48	0.04	1	0.25	0.24	0.19	0.30	0.12
Syrphid	0.39	0.23	0.23	0.27	0.28	0.28	0.29	0.29	0.01	0.25	1	0.07	0.06	0.06	-0.06
Butterfly	0.54	0.21	0.28	0.34	0.39	0.44	0.45	0.43	0.22	0.24	0.07	1	0.14	0.20	0.03
Carabid	0.56	0.07	0.21	0.33	0.41	0.45	0.46	0.45	0.21	0.19	0.06	0.14	1	0.34	-0.02
Spider	0.64	0.22	0.31	0.40	0.48	0.54	0.59	0.57	0.18	0.30	0.06	0.20	0.34	1	0.15
Bird	0.37	0.61	0.59	0.54	0.50	0.46	0.43	0.44	0.00	0.12	-0.06	0.03	-0.02	0.15	1

1134
 1135 Data for bee species richness were only available for 183 landscapes. To determine whether
 1136 this affected our results, we also calculated the multidiversity index across six taxa (all groups except
 1137

1138 bees). As there was no difference in results obtained with six or seven taxa, we here only present
1139 results for the multidiversity index calculated across seven taxa within 435 landscapes.

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1142 **References**

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SI 4 – Land cover mapping and landscape metrics

4.1. Land cover mapping

Land cover was mapped based on remotely-sensed data and ground-truthing. All cover types, including fields, linear elements between fields and non-agricultural cover types, were mapped as polygons ('patches') (Fig. S4.1). We here refer to 'cover types' rather than 'habitats' because 'habitat' refers to the specific ecological requirements of a given species while 'cover type' refers to a category of land cover without any assumption on species use. This is important in the present study where we assume that many farmland species are likely to use several cover types (landscape complementation).

Agricultural cover types included: cereal, fallow, alfalfa, clover, ryegrass, rice, corn, sunflower, sorghum, millet, moha, oilseed rape, mustard, pea, bean, soybean, linseed, orchard, almond, olive, vineyard, mixed vegetables, sugar beet, asparagus, carrot, onion, parsnip, potato, tomato, melon, strawberry, raspberry, wild bird cover, grassland (including temporary and permanent grassland managed for production purpose) and other crops (unknown or rare crops). We chose to include managed grassland within agricultural cover types because we were interested in assessing the role of spatial heterogeneity within the farmed part of the landscape. We considered grasslands where more than 50% of the biomass was removed as agricultural cover whereas those where less than 50% of the biomass was removed were considered as non-agricultural cover. Linear elements between fields were classified either as woody, grassy, water (e.g. ditches) or tracks. Non-agricultural cover types included woodland (including woody linear elements), open land (e.g. shrubland, grassy linear elements), wetland and built-area (including roads).



Figure S4.1. Example of land cover map used to calculate variables within each landscape (1km x 1km).

4.2. Landscape metrics

It is well known that different taxa and even species are likely to respond to the landscape structure at different spatial scales. Since our aim was to assess the overall effects of crop diversity and mean field size on a range of contrasted taxa, we chose to calculate landscape variables within a 1x1 km because this spatial extent represent the best compromise between highly mobile taxa (e.g. birds) and taxa with more limited dispersal abilities (e.g. plants or spiders; Kormann et al. 2015).

4.2.1. Number of crop types sampled

The number of crop types sampled ranged from one to three. The diversity of crop types available in the landscape and the number of crop types sampled within each landscape were not heavily correlated ($r=0.45$).

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4.2.2. Crop compositional heterogeneity

We used the diversity of crop types available in the landscape (hereafter ‘crop diversity’) as a measure of crop compositional heterogeneity. We measured crop diversity using the Shannon diversity index, a widely used metric of landscape heterogeneity (e.g. Bertrand et al. 2016; Bosem Baillod et al. 2017): $H' = -\sum_{i=1}^n p_i \ln p_i$ where p_i is the proportion of crop type i in the agricultural mosaic. Note that this metric assumes that all agricultural cover types (defined in 4.1) are considered equally different. This variable does not take into account within-field crop heterogeneity, e.g. intercropping patterns.

The diversity of crop types available in the landscape and the number of crop types sampled within each landscape were not heavily correlated ($r=0.45$).

4.2.3. Crop configurational heterogeneity

We used mean field size (ha) as a measure of crop configurational heterogeneity. We chose this metric over total field perimeter length per landscape (e.g. Bosem Baillod et al. 2017) because it is directly related to our hypotheses (see SI 1). Moreover it is easier to base practical recommendations for future agricultural policies on mean field size rather than on total field perimeter length. Fields were only mapped within the 1 km² landscape. As a result, for fields located partly outside of the 1 km² landscape, only their area contained within the landscape was considered in calculating mean field size. This may lead to a slight underestimation of mean field size.

4.2.4. Semi-natural cover proportion

We calculated the sum of woodland (including woody linear elements), open land (e.g. shrubland, grassy margins) and wetland cover (including ponds, rivers, ditches) in the landscape.

4.2.5. Total length of semi-natural linear elements

We assessed the total length of vegetation occurring in semi-natural linear elements between fields (SNL, in meters) by calculating half the sum of all semi-natural linear elements located between two fields (e.g. hedgerows, grassy margins). Note that semi-natural linear elements located along roads or urban areas were not included in the calculation of SNL. SNL and mean field size were highly correlated (see Table S5.5. in SI 5).

4.2.6. Latitude and longitude

We calculated the latitude and longitude of the center of each landscape using the WGS 1984 World Mercator projection system.

4.3. Descriptive statistics for the 435 landscapes selected

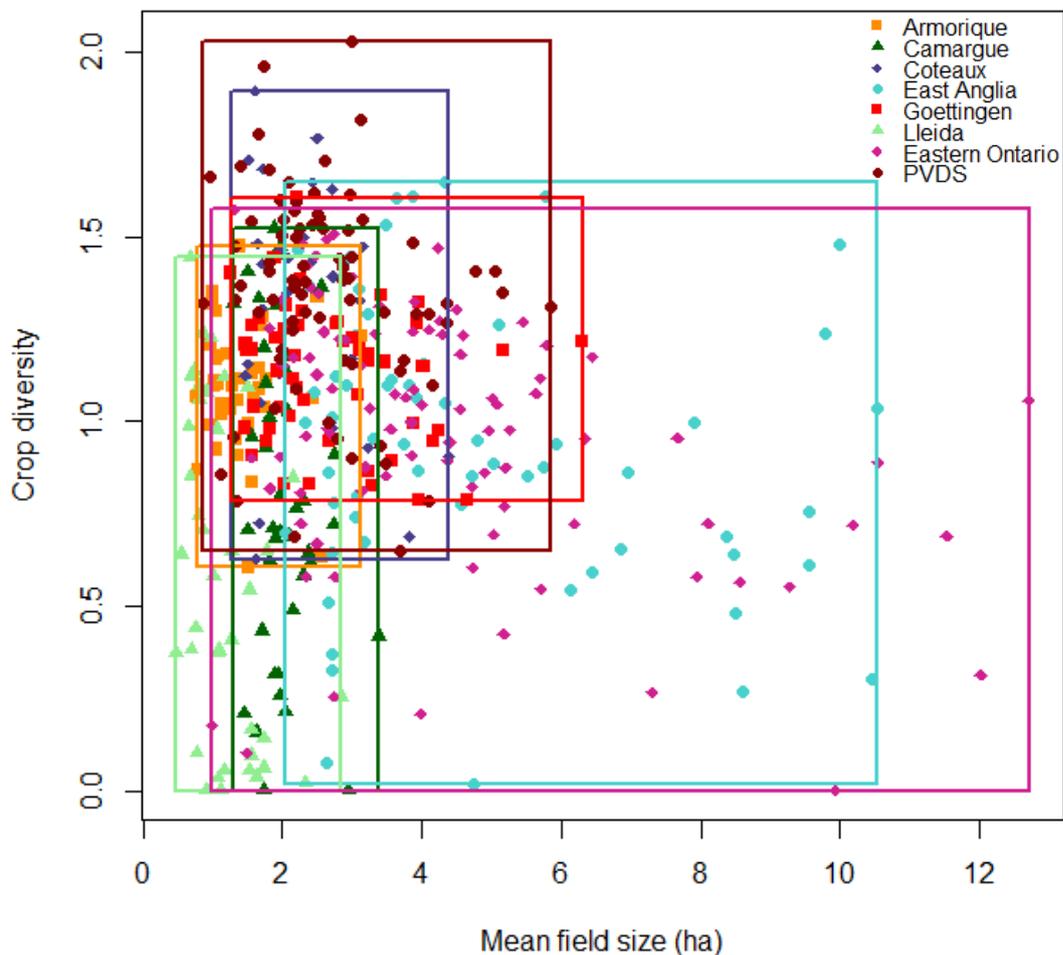
The 435 landscapes selected across eight regions of Europe and North America had the following characteristics (mean \pm sd; see also Table S4.1): 1.94 \pm 0.56 crop types sampled, 81.3 \pm 9.6 % of agricultural cover, 12.7 \pm 8.9 % of semi-natural cover, 5631 \pm 3822 m of linear semi-natural elements between fields, mean field size 2.99 \pm 2.02 ha and a Shannon diversity index of agricultural cover types of 1.03 \pm 0.39 (Fig S4.3). These gradients are representative of most Western European agricultural landscapes (Herzog et al. 2006) and most American agricultural landscapes (Yan & Roy 2016).

Table S4.1. Descriptive statistics for each landscape variable (mean, median, 25th and 75th quartiles, min and max): number of crop types sampled (Crop nb), diversity of crop types available in the landscape (Crop diversity), mean field size (ha), the percentage of semi-natural cover types (SNC), and the length of semi-natural linear elements (SNL).

Crop nb	Crop diversity	Mean field size (ha)	SNC (%)	SNL (m)
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Min	1	0.0	0.48	0.0	0
1st quartile	2	0.8	1.71	6.0	3108
Median	2	1.09	2.43	10.9	4824
Mean	1.94	1.03	2.99	12.7	5632
3rd quartile	3	1.31	3.69	17.6	7370
Max	3	2.03	12.71	49.5	27989

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1262 **Figure S4.3.** Variation in crop diversity and mean field size (ha) across the eight regions. Points
 1263 correspond to selected landscapes (N= 435) and boxes corresponds to the range of crop diversity and
 1264 mean field size sampled within each region (orange=Armorique, dark green=Camargue, dark
 1265 blue=Coteaux, light blue=East Anglia, light red=Goettingen, light green=Lleida, pink=Eastern Ontario,
 1266 dark red=PVDS).

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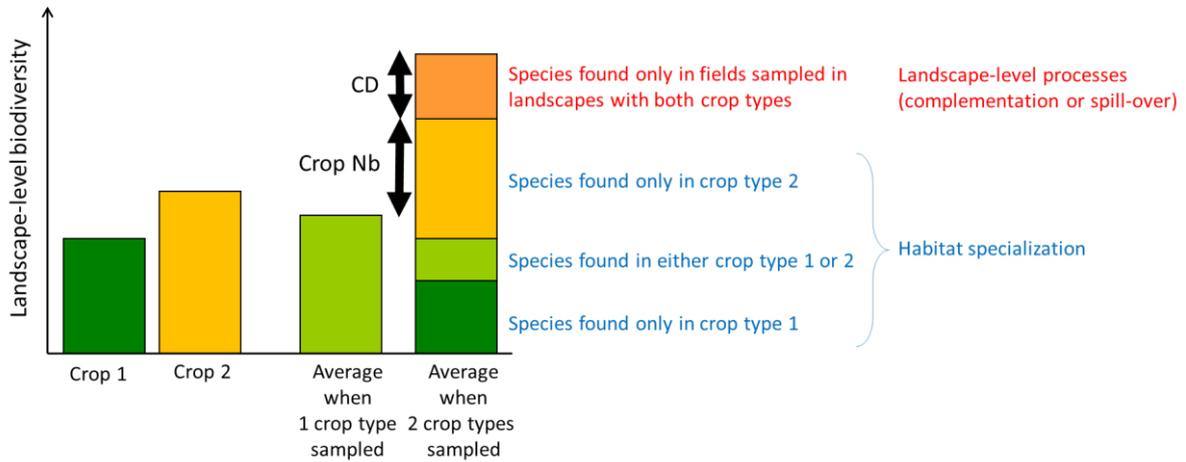
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1269 4.4. Effects of the number of crop types sampled vs. the diversity of crop types in the landscape

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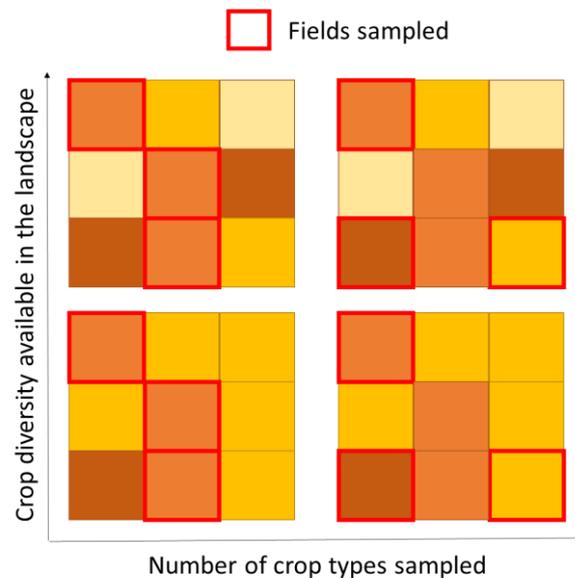
1271 Biodiversity may increase with increasing crop diversity if different crop types can serve as
 1272 habitat for different specialized species (single habitat specialization; Fig. S4.4). In that case, sampling
 1273 more crop types will result in higher observed landscape-level multitrophic diversity. Biodiversity
 1274 may also increase with crop diversity if different crop types provide different resources required for

1275 single species (landscape complementation). In that case, sampling the same number of crop types in
 1276 landscapes with higher crop diversity will result in higher landscape-level multitrophic diversity.
 1277



1278
 1279 **Figure S4.4.** Roles of habitat specialization, landscape complementation or spill-over in the potential
 1280 positive effect of crop diversity on multitrophic diversity (see SI 1). Black arrows represent the effect
 1281 of our two explanatory variables (CD = increasing the diversity of crop types in the landscape; Crop
 1282 Nb = increasing the number of crop types sampled).
 1283

1284 Since the diversity of crop types available in the landscape and the number of crop types
 1285 sampled within each landscape were not heavily correlated ($r=0.45$), we were able to disentangle the
 1286 role of these two mechanisms (Fig. S4.5).
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 1289 **Figure S4.5.** Representation of our sampling design allowing us to take into account the potential
 1290 contribution of habitat specialization and landscape complementation/spillover to the positive effect
 1291 of crop diversity on multitrophic diversity.
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1306 **SI 5 – Complementary analyses**

1307

1308 **5.1. Details of the model selection and model averaging for multitrophic diversity**

1309

We first tested the effect of crop heterogeneity on multitrophic diversity (Model 1).

1311

1312 *Model 1: lmer (T60.landscape ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon + (1|*
 1313 *Region/Year))*

1314

1315 The model selection approach based on $\Delta AICc < 2$ resulted in the selection of 10 sub-models
 1316 (Table S5.1). Using a $\Delta AICc$ of 7 did not change the results of the model averaging or results on
 1317 variable importance. All models included crop diversity (CD), mean field size (MFS), semi-natural
 1318 cover (SNC), the number of crops sampled per landscape (Crop nb) and the interaction between crop
 1319 diversity and semi-natural cover (CD x SNC). The AICc of the Null model was 3709 while the AICc of
 1320 the best model was 3667, i.e. a $\Delta AICc$ of 42, suggesting that the best selected models were far more
 1321 parsimonious than the null model including only Region and Year as random effects.

1322

1323 **Table S5.1.** List of all sub-models selected and used for the model averaging approach for model 1.

Sub-model	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10	Null
Lat											
Lon											
CD											
CD ²											
MFS											
MFS ²											
SNC											
Crop nb.											
CD x SNC											
MFS x SNC											
CD x MFS x SNC											
Marginal R ²	0.13	0.13	0.12	0.15	0.15	0.12	0.14	0.12	0.14	0.13	0
Conditional R ²	0.36	0.37	0.35	0.38	0.38	0.36	0.37	0.37	0.37	0.36	0.23
df	10	11	9	11	12	10	10	11	11	11	–
AICc	3667.5	3668.09	3668.16	3668.21	3668.75	3668.75	3668.86	3669.36	3669.39	3669.56	3709.7
delta	0	0.59	0.66	0.7	1.24	1.24	1.35	1.85	1.89	2.05	42.23
weight	0.17	0.13	0.12	0.12	0.09	0.09	0.09	0.07	0.07	0.06	–

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1327 **5.2. Influence of selected threshold on parameter estimates for multitrophic diversity**

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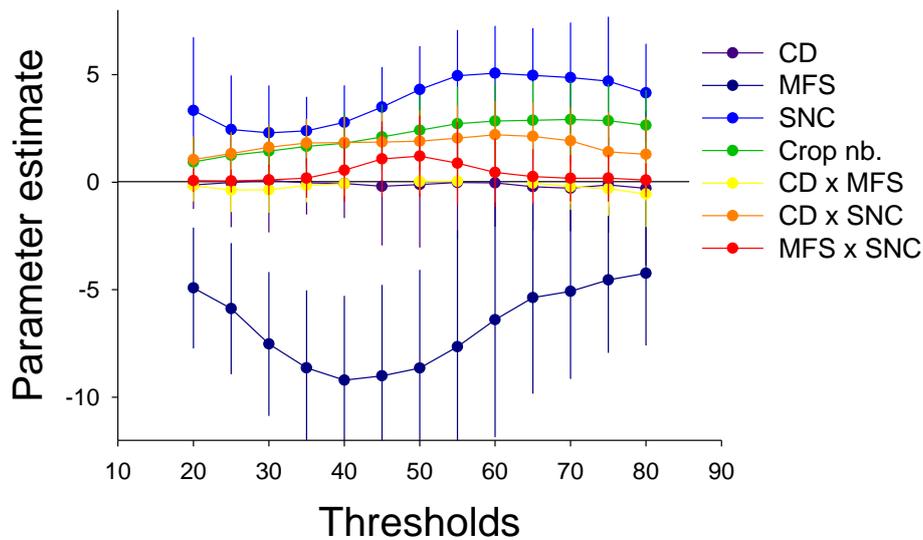
1329 To test whether the choice of threshold for computing the multitrophic diversity index
 1330 impacted our conclusions, we ran model 2 for all thresholds from T20 to T80 (i.e. proportion of taxa
 1331 for which the species richness is equal to or higher than 20% to 80% of the regional maximum species
 1332 richness per landscape).

1333

1334 Parameters estimates were consistent across the range of thresholds (Fig. S5.1). Moreover,
 1335 variations in parameter estimates suggests that increasing mean field size may be particularly
 1336 effective to reach intermediate multidiversity thresholds (i.e. between 30 and 50% of regional
 1337 maximum) whether increasing semi natural cover may be effective to reach higher multidiversity
 1338 threshold (i.e. above 50% of regional maximum).

1339

1340 This comparison confirms the validity of choosing T60.landscape, i.e. the proportion of taxa
 for which the species richness is equal or higher than 60% of the regional maximum species richness
 per landscape.



1341
 1342 **Figure S5.1.** Parameter estimates based on model 1 for different thresholds. Thresholds correspond
 1343 to the % of SR max used to calculate the multidiversity index. In this paper, we present model
 1344 outcomes for a threshold of 60%, i.e. we use the proportion of taxa that exceeded 60% of the
 1345 maximum species richness.

1346
 1347
 1348 **5.3. Variation in the response of multitrophic diversity among regions**

1349
 1350 To test whether the effects of crop diversity, mean field size and semi-natural cover on
 1351 multitrophic diversity measured at the landscape level (T60.landscape) varied significantly among
 1352 regions we added random effects for region on the slopes of crop diversity, mean field size, semi-
 1353 natural cover as well as the interaction between crop diversity and semi-natural cover (model 2). We
 1354 assumed that the effects of region on the intercept and slopes were uncorrelated. To test whether
 1355 Region had a significant effect on the slope of either crop diversity, mean field size, semi-natural
 1356 cover as well as the interaction between crop diversity and semi-natural cover, we used the function
 1357 exactRLRT from package RLRsim.

1358 *Model 2: Imer (T60.landscape ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon +*
 1359 *(1|Region/Year) + (0+CD|Region)) + (0+MFS|Region) + (0+SNC|Region) + (0+CD:SNC|Region))*

1360 **Table S5.2.** Comparison of model 1 and model 2 (i.e. model including a random effect of region on
 1361 slope). Parameter listed are those retained in the model selection procedure. Parameter estimates
 1362 and confidence intervals are based on the model averaging approach. ° p<0.1; * p<0.05; ** p<0.01;
 1363 *** p<0.001.

	model 1	model 2
Crop diversity (CD)	-0.03 [-2.07 ; 2.01]	-0.16 [-2.22 ; 1.9]
Mean field size (MFS)	-6.39 [-11.85 ; -0.94] *	-5.22 [-11.29 ; 0.85] °
Semi-Natural Cover (SNC)	5.07 [2.87 ; 7.26] ***	4.35 [0.79 ; 7.91] *
Nb of Crops sampled	2.84 [1.07 ; 4.62] ***	3.05 [1.29 ; 4.8] ***
Latitude	1.5 [-3.55 ; 6.55]	
Longitude	3.73 [2.47 ; 9.93]	-2.39 [-8.39 ; 3.62]
MFS ²	3.78 [-0.67 ; 8.23] °	3.78 [-2.26 ; 9.83]
SNC ²		-2.39 [-8.39 ; 3.62]
CD :SNC	2.20 [0.64 ; 3.76] **	2.06 [0.29 ; 3.82] *
MFS :SNC	1.15 [-0.66 ; 2.96]	1.51 [-0.44 ; 3.46]

1365

1366 The random effect of region on the slope of MFS was significant in model 2 (RLRT = 3.28,
1367 p=0.02) whereas the effects on CD (RLRT=0, p=1), SNC (RLRT=0.04, p=0.33) and CD:SNC (RLRT=0.19,
1368 p=0.24) were not (Fig. 4). This result confirms that the regional context can modulate the effect of
1369 mean field size on multitrophic diversity, but that the positive effects of increasing CD, when SNC is
1370 high enough, and decreasing MFS remain valid across all regions (Table S5.2).

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1372 5.4. Results on the species richness of taxonomic groups

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1374 We tested the effects of crop heterogeneity on the species richness of taxonomic groups
1375 (Model 3). To do this, we fitted a similar model, using the landscape-level species richness of
1376 taxonomic groups (SR) as the response variable. To reflect that species pools vary between taxa, we
1377 added Taxon as a random effect.

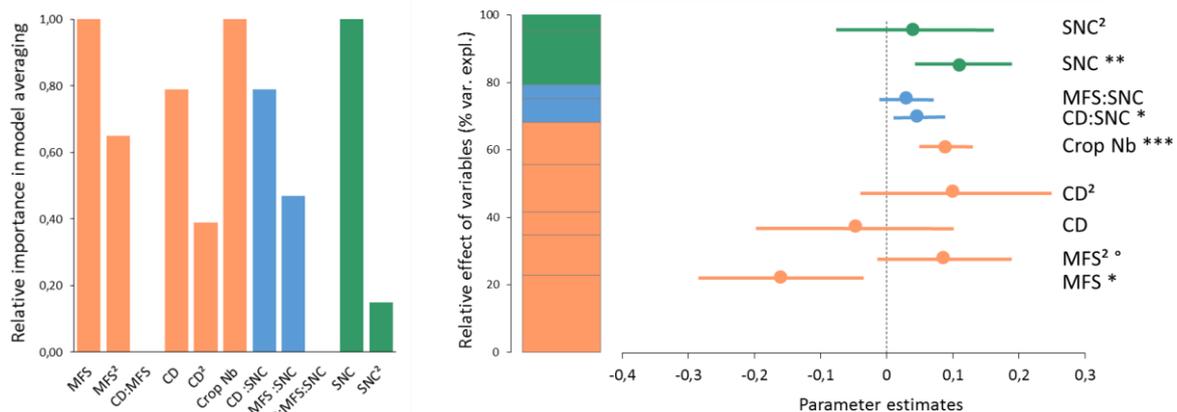
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1379 *Model 3: lmer (SR ~ CD*MFS*SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon + (1|Region/Year) +*
1380 *(1|Taxon))*

1381

1382 The effects of crop heterogeneity on the species richness of taxonomic groups were similar
1383 to their effects on multitrophic diversity (Fig. S5.2).

1384



1385

1386 **Figure S5.2.** Response of the species richness of taxonomic groups to the diversity of crop types
1387 available within the landscape (CD), the number of crops sampled (Crop Nb), mean field size (MFS),
1388 semi-natural cover (SNC), and interaction terms (CD:SNC, MFS:SNC, see further details in Methods),
1389 based on data collected in 435 landscapes located in eight agricultural regions. Covariates (Lon, Lat)
1390 were excluded from the figure for simplicity. Importance of each variable in the model averaging
1391 approach (model 3), estimated as the proportion of models where the variable was selected. The
1392 relative effect of each variable corresponds to the ratio between its parameter estimate and the sum
1393 of all parameter estimates (i.e. the % of variance explained). Parameter estimates and confidence
1394 intervals, based on a model averaging approach applied to model 3 (Methods). ° p<0.1; * p<0.05; **
1395 p<0.01; *** p<0.001. Variables are grouped in three components: orange = crop heterogeneity (MFS,
1396 MFS², CD, CD², MFS:CD, Crop Nb), green = semi-natural cover (SNC, SNC²), blue = interactive effects
1397 between crop heterogeneity and semi-natural cover (CD:SNC, MFS:SNC, CD:MFS:SNC).

1398

1399 To test whether the effects of crop diversity, mean field size and semi-natural cover on the
1400 species richness of taxonomic groups varied significantly among taxa we added random effects for
1401 Taxon on the slopes of crop diversity, mean field size, semi-natural cover as well as the interaction
1402 between crop diversity and semi-natural cover (model 4). We assumed that the effects of Taxon on

1403 the intercept and slopes were uncorrelated. To test whether Taxon had a significant effect on the
 1404 slope of either crop diversity, mean field size, semi-natural cover or the interaction between crop
 1405 diversity and semi-natural cover, we used the function exactRLRT from package RLRsim.

1406 *Model 4: Imer (SR ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon + (1|Taxon) +*
 1407 *(1|Region/Year) + (0+CD|Taxon)) + (0+MFS|Taxon) + (0+SNC|Taxon) + (0+CD:SNC|Taxon))*

1408 **Table S5.3.** Comparison of model 3 and model 4 (i.e. model including a random effect of taxa on
 1409 slopes). Parameter listed are those retained in the model selection procedure. Parameter estimates
 1410 and confidence intervals are based on the model averaging approach. ° p<0.1; * p<0.05; ** p<0.01;
 1411 *** p<0.001.

	model 3	model 4
Crop diversity (CD)	-0.05 [-0.2 ; 0.11]	-0.05 [-0.21 ; 0.1]
Mean field size (MFS)	-0.16 [-0.28 ; -0.04] *	-0.14 [-0.26 ; -0.03] *
Semi-Natural Cover (SNC)	0.11 [0.04 ; 0.18] **	0.11 [0.06 ; 0.17] ***
Nb of Crops sampled	0.09 [0.05 ; 0.13] ***	0.09 [0.05 ; 0.13] ***
Latitude	0.07 [-0.03 ; 0.16]	0.06 [-0.03 ; 0.16]
CD ²	0.1 [-0.04 ; 0.24]	0.08 [-0.07 ; 0.23]
MFS ²	0.08 [-0.02 ; 0.19] °	0.07 [-0.03 ; 0.17]
SNC ²	0.04 [-0.08 ; 0.16]	0.01 [-0.11 ; 0.13]
CD :SNC	0.04 [0.01 ; 0.08] *	0.05 [0.002 ; 0.09] *
MFS :SNC	0.03 [-0.01 ; 0.07]	0.03 [-0.01 ; 0.07]

1413

1414 The random effect of taxa on the slope of CD (RLRT = 1.94, p=0.06), MFS (RLRT=0.05, p=0.34),
 1415 SNC (RLRT=0.26, p=0.24) and CD:SNC (RLRT=0.35, p=0.22) were not significant in model 4 (Fig. 5).
 1416 This result confirms that the effects of crop heterogeneity on species diversity vary only marginally
 1417 among taxa, and that the positive effects of decreasing mean field size, increasing the number of
 1418 crop sampled, increasing semi-natural cover, and when semi-natural cover is high, increasing crop
 1419 diversity, remain valid across all taxa (Table S5.3).

1420

1421

1422 **5.5. Correlations and alternative mechanisms at the landscape level**

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1424 Crop diversity and mean field size are likely to be correlated with several variables, including
 1425 the overall composition of the crop mosaic, the proportion of grassland in the mosaic or the length of
 1426 semi-natural vegetation occurring between fields. Disentangling the role of crop heterogeneity from
 1427 the effects of these other variables is necessary in order to infer potential mechanisms explaining the
 1428 positive effect of crop heterogeneity on multitrophic diversity. In the present study, some of these
 1429 additional variables were correlated among themselves, or with our variables of interest. Exploring
 1430 their role sometimes required running models using a data subset for which relevant variables were
 1431 uncorrelated. As a result, we could not include all these variables in a single model and present these
 1432 analyses as separate, complementary analyses.

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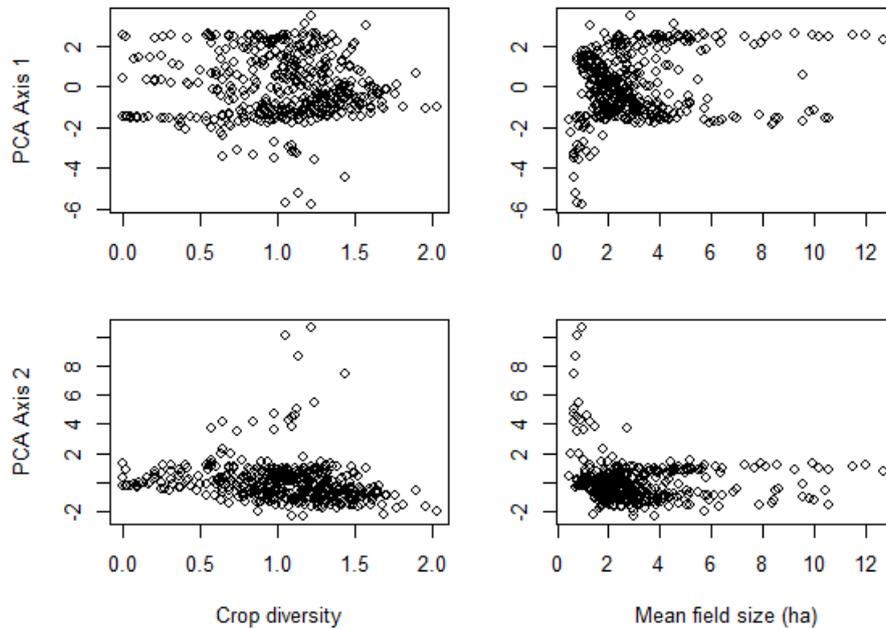
1434 **5.5.1. Role of the identity of crops in the agricultural mosaic**

1435 The identity of crop types in the mosaic may vary along the gradients of crop diversity and
 1436 mean field size. For instance, landscapes with small fields may be composed of more biodiversity-
 1437 friendly crops. Such a correlation would represent a potential bias in our study and hamper our
 1438 ability to test the effects of crop heterogeneity on multitrophic diversity.

1439 We investigated the correlation between each crop heterogeneity gradient and the identity
 1440 of crop types in the mosaic for 435 landscapes from 8 regions. We conducted a Principal Components

1441 Analysis on the matrix of percentage cover per agricultural cover type per landscape. The first axis
 1442 represented 40% of the variance, while the second axis represented 19% of the variance.

1443 The Pearson correlations between crop diversity and the first two axes of the PCA were weak
 1444 (axis 1: $r=-0.03$, $p=0.56$ and axis 2: $r=-0.19$, $p<0.001$), as were the Pearson correlations between mean
 1445 field size and the first two axes of the PCA (axis 1: $r=0.21$, $p<0.001$ and axis 2: $r=-0.12$, $p=0.01$; Fig.
 1446 S5.3).



1448 **Figure S5.3.** Relationships between the two crop heterogeneity gradients and the identity of crop
 1449 types in the mosaic (axes 1 and 2 of the Principal Components Analysis).

1452 We added the scores of landscapes along axes 1 and 2 of the PCA to model 1 and compared
 1453 the outcomes of the obtained model (model 3) with those of model 1.

1454 *Model 1: $Imer(T60.landscape \sim CD * MFS * SNC + CD^2 + MFS^2 + SNC^2 + CropNb + Lat + Lon + (1 |$*
 1455 *Region/Year))*

1456 *Model 5: $Imer(T60.landscape \sim CD * MFS * SNC + CD^2 + MFS^2 + SNC^2 + CropNb + Lat + Lon + Axis1 +$*
 1457 *Axis 2 + (1 | Region/Year))*

1460 The average model selected based on model 5 included the same variables as the average
 1461 model selected based on model 1, plus variable PCA Axis 1. Parameter estimates and significance for
 1462 variables of interest remained unchanged (Table S5.4). This result suggests that the effects of CD, in
 1463 combination with SNC, and MFS cannot be explained by the composition of crop types occurring in
 1464 the mosaic.

1465 **Table S5.4.** Comparison of estimates for model 1 and model 5 – mosaic crop composition (i.e. model
 1466 taking into account the composition of crop types in the mosaic). Parameter listed are those retained
 1467 in the model selection procedure. Parameter estimates and confidence intervals are based on the
 1468 model averaging approach. ° $p<0.1$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

	model 1	model 5 – mosaic crop composition
Crop diversity (CD)	-0.03 [-2.07 ; 2.01]	-0.06 [-2.1 ; 1.96]
Mean field size (MFS)	-6.39 [-11.85 ; -0.94] *	-6.44 [-11.88 ; -1.01] *
Semi-Natural Cover (SNC)	5.07 [2.87 ; 7.26] ***	5.07 [2.88 ; 7.27] ***
Nb of Crops sampled	2.84 [1.07 ; 4.62] ***	2.84 [1.06 ; 4.62] **

Latitude	1.5 [-3.55 ; 6.55]	1.5 [-3.55 ; 6.55]
Longitude	3.73 [2.47 ; 9.93]	3.73 [-2.47 ; 9.93]
MFS ²	3.78 [-0.67 ; 8.23] °	3.73 [-0.72 ; 8.19]
CD :SNC	2.20 [0.64 ; 3.76] **	2.21 [0.65 ; 3.77] **
MFS :SNC	1.15 [-0.66 ; 2.96]	1.15 [-0.66 ; 2.96]
PCA axis 1		1.5 [-3.55 ; 6.55]

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5.5.2. Role of the proportion of grassland in the crop mosaic

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*Model 6: Imer (T60.landscape ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon + Grassland + (1 | Region/Year))*

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Model selection based on model 6 included the same variables as for model 1, plus Grassland, which had a marginally significant positive effect. However, parameter estimates and significance for other variables of interest remained unchanged (Table S5.5). This result suggests that the effects of CD, in combination with SNC, and MFS cannot be explained by the proportion of grassland in the mosaic.

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Table S5.5. Comparison of model 1 and model 6 – grassland (i.e. complete model taking into account the proportion of grassland in the mosaic). Parameter listed are those retained in the model selection procedure. Parameter estimates and confidence intervals are based on the model averaging approach. ° p<0.1; * p<0.05; ** p<0.01; *** p<0.001.

	model 1	model 6 – grassland
Crop diversity (CD)	-0.03 [-2.07 ; 2.01]	0.18 [-1.9 ; 2.26]
Mean field size (MFS)	-6.39 [-11.85 ; -0.94] *	-6.2 [-11.83 ; -0.59] *
Semi-Natural Cover (SNC)	5.07 [2.87 ; 7.26] ***	5.07 [2.88 ; 7.27] ***
Nb of Crops sampled	2.84 [1.07 ; 4.62] ***	2.73 [0.94 ; 4.52] **
Latitude	1.5 [-3.55 ; 6.55]	
Longitude	3.73 [2.47 ; 9.93]	4.07 [-2.34 ; 10.47]
MFS ²	3.78 [-0.67 ; 8.23] °	3.98 [-0.48 ; 8.44] °
CD :SNC	2.20 [0.64 ; 3.76] **	2.25 [0.69 ; 3.81] **
MFS :SNC	1.15 [-0.66 ; 2.96]	1.33 [-0.51 ; 3.16]
Grassland		1.87 [-0.26 ; 4.00] °

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5.5.3. Role of semi-natural vegetation occurring between fields

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Mean field size (MFS in ha) and the length of semi-natural linear elements between fields (SNL) or the length of hedgerows (H) were strongly correlated, particularly in some regions (e.g. Armorique, Table S5.6). As a result, we could not include both MFS and SNL (or MFS and H) in our models and disentangle their effects on multitrophic diversity.

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Table S5.6. Pearson correlation coefficients among explanatory variables across and within regions. CD = crop diversity, MFS = mean field size, SNC= proportion of semi-natural cover, SNL= length of semi-natural linear elements between fields, H = length of hedgerows between fields. N = number of landscapes. Correlations between H and CD or SNC were low and are not shown here for simplicity.

	CD-MFS	CD-SNC	CD-SNL	MFS-SNC	MFS-SNL	MFS-H	SNC-SNL	N
All regions	-0.13	-0.27	-0.30	-0.02	-0.44	-0.37	0.13	435
Armorique	-0.03	0.09	0.10	-0.01	-0.71	-0.67	-0.06	40
Camargue	-0.20	-0.25	0.11	-0.06	-0.55	-0.17	-0.59	40
Coteaux	-0.27	-0.22	0.51	-0.31	-0.57	-0.50	-0.24	32
East Anglia	-0.18	0.21	0.18	-0.16	-0.34	-0.23	-0.41	60
Goettingen	-0.17	0.15	0.05	0.15	-0.43	-0.10	-0.10	52
Lleida	-0.40	-0.14	0.16	-0.15	-0.50	-0.23	-0.20	40
Eastern Ontario	-0.34	-0.13	0.27	-0.40	-0.53	-0.43	-0.08	93
PVDS	-0.16	-0.08	-0.02	-0.37	-0.51	-0.57	0.29	78

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To test whether our results for MFS were likely due to the correlation with SNL or H, we selected a subset of landscapes for which explanatory variables, in particular MFS and SNL as well as MFS and H, were uncorrelated i.e. with a Pearson correlation coefficient <0.56 for each pair of explanatory variables, within each region (Table S5.7).

Table S5.7. Pearson correlation coefficients among explanatory variables, across and within regions, within the subset of landscapes (274 landscapes) used to test for the influence of SNL and H on our results for the effects of crop heterogeneity. CD = crop diversity, MFS = mean field size, SNC= proportion of semi-natural cover, SNL= length of semi-natural linear elements between fields, H = length of hedgerows between fields. N = number of landscapes.

	CD-MFS	CD-SNC	CD-SNL	MFS-SNC	MFS-SNL	MFS-H	SNC-SNL	N
All regions	-0.15	-0.30	-0.40	-0.08	-0.27	-0.28	0.30	274
Armorique	-0.02	0.29	0.40	-0.06	-0.04	-0.15	-0.33	20
Camargue	-0.25	-0.19	-0.14	-0.56	-0.05	-0.15	-0.09	20
Coteaux	0.31	-0.38	0.20	-0.46	0.06	-0.12	-0.52	20
East Anglia	-0.15	-0.04	0.35	-0.32	-0.18	-0.31	-0.40	43
Goettingen	-0.26	0.10	0.10	-0.02	-0.22	-0.01	-0.07	45
Lleida	-0.33	0.08	-0.51	-0.37	0.24	-0.20	0.08	20
Eastern Ontario	-0.18	-0.07	-0.03	-0.43	-0.21	-0.32	-0.32	44
PVDS	-0.16	-0.15	-0.08	-0.41	-0.28	-0.46	0.29	62

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We built a model similar to model 1 including both SNL and MFS in order to disentangle their effects on multitrophic diversity:

*Model 7: Imer (T60.landscape ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon + SNL + (1|Region/Year))*

Model selection based on model 7 included the same variables as for model 1 (except Latitude and SNC²), plus SNL. SNL was marginally significant. Parameter estimates and significance for variables of interest remained unchanged (Table S5.8). This results does not confirm the general assumption that the positive effect of MFS is only due to the positive effect of the amount of SNL.

Our variable SNL included a variety of semi-natural linear elements (e.g. hedgerows, grassy margins) that may not play the same role for biodiversity. Therefore, we built another model similar

1539 to model 7 including the length of hedgerows (Hedgerow) instead of SNL in order to test whether the
 1540 effect of MFS on multitrophic diversity may be due to the increase in the length of hedgerows:

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 1542 *Model 8: lmer (T60.landscape ~ CD * MFS * SNC + CD² + MFS² + SNC² + CropNb + Lat + Lon +*
 1543 *Hedgerows + (1 | Region/Year))*

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 1545 Model selection based on model 8 included the same variables as for model 1 (except SNC²
 1546 and MFS:SNC), plus Hedgerows. Hedgerows were non-significant. Parameter estimates and
 1547 significance for variables of interest remained unchanged (Table S5.8). This results does not confirm
 1548 the general assumption that the positive effect of MFS is only due to the positive effect of the
 1549 amount of SNL or hedgerows. Instead, this result lends support to the idea that agricultural
 1550 landscapes with smaller fields provide better access to different field types for species that require
 1551 landscape complementation.

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 1553 **Table S5.8.** Comparison of models 1, 7 (with SNL) and 8 (with Hedgerows) based on the uncorrelated
 1554 subset of landscapes. Parameter listed are those retained in the model selection procedure.
 1555 Parameter estimates and confidence intervals are based on the model averaging approach. ° p<0.1; *
 1556 p<0.05; ** p<0.01; *** p<0.001.

	model 1 (subset)	model 7 – SNL	model 8 – Hedgerows
Crop diversity (CD)	-0.14 [-2.9 ; 2.62]	0.39 [-2.39 ; 3.17]	-0.03 [-2.8 ; 2.74]
Mean field size (MFS)	-9.9 [-18.1 ; -1.68] *	-8.92 [-17.24 ; -0.61] *	-8.28 [-16.94 ; 0.38] °
Semi-Natural Cover (SNC)	3.09 ; 0.15 ; 6.03] *	3.16 [0.25 ; 6.07] *	3.17 [0.21 ; 6.14] *
Latitude		2.94 [-3.03 ; 8.9]	
Longitude	2.61 [-2.01 ; 8.89]	2.06 [-4.5 ; 8.62]	2.74 [-4.1 ; 9.58]
MFS ²	6.71 [-0.07 ; 13.49] °	6.54 [-0.16 ; 13.24] °	6.33 [-0.44 ; 13.11] °
SNC ²		2.71 [0.14 ; 5.34] *	2.6 [-0.03 ; 5.24] °
Nb of Crops sampled	3.87 [1.58 ; 6.17] ***	4.28 [1.98 ; 6.58] ***	3.86 [1.57 ; 6.15] **
CD :SNC	1.85 [-0.28 ; 3.98] °	1.79 [-0.31 ; 3.89] °	1.83 [-0.29 ; 3.96] °
MFS :SNC	0.66 [-2.01 ; 3.32]	0.83 [-1.81 ; 3.47]	
SNL		3.64 [-0.06 ; 7.34] °	
Hedgerows			2.69 [-0.22 ; 5.56] °

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1559 5.6 Correlations and alternative mechanisms at the field level

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1561 Crop diversity and mean field size are also likely to be correlated with several variables at the field
 1562 level, including the identity of crops sampled, the local land-use intensity (e.g. herbicide use,
 1563 ploughing frequency). Disentangling the role of crop heterogeneity from the effects of these other
 1564 variables is also necessary in order to infer potential mechanisms explaining the positive effect of
 1565 crop heterogeneity on multitrophic diversity. This required running models at the field level, using a
 1566 data subset for which co-variable data were available. As a result, we could not include all these
 1567 variables in a single model and therefore present these analyses as separate, complementary
 1568 analyses.

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1570 5.6.1. Role of the identity of sampled crop types

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1572 We tried to limit correlations between the two crop heterogeneity gradients and the identity
 1573 of sampled crop types. In some cases, correlations were impossible to avoid because some crops
 1574 occurred or were dominant only in some regions (e.g. rice in Camargue, almond and olive in Lleida)
 1575 or some landscapes (e.g. landscapes with low crop compositional heterogeneity). As a result,
 1576 different types of crop sampled were associated with significantly different values of crop diversity or
 1577 mean field size (Table S5.9).

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Table S5.9. Analysis of variance showing the relationship between the two heterogeneity gradients (crop diversity and mean field size) and sampled crop type within each region. Since sampled crop type is a categorical variable, correlation coefficient cannot be used. We therefore used the function aov in R, crop diversity and mean field size being the response variables and sampled crop type being the predictor variable. Values correspond to the F value of the function aov in R. * p<0.05; ** p<0.01; *** p<0.001.

	Crop diversity	Mean field size
All regions	5.78***	9.28***
Armorique	1.95	0.29
Camargue	8.54**	0
Coteaux	1.16	0.59
East Anglia	3.35***	1.29
Goettingen	0	0
Lleida	9.43***	2.18
Eastern Ontario	2.57*	2.61**
PVDS	0.35	0.53

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To evaluate whether the sampled crop type influenced our results, we built a model similar to model 1 but using multidiversity calculated at the field level as the response variable (T60.field). We compared models with and without adding crop type as a random effect (using data collected in 1305 fields in 435 landscapes from 8 regions). Crop type was added as a random effect because we were not interested in estimating the specific effect of each particular crop type. Note there were enough crop types (16) to estimate the random effect adequately.

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*Model 9: lmer (T60.field ~ CD * MFS * SNC + CD² + MFS² + SNC² + Lat + Lon + (1|Region/Year/Landscape))*

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*Model 10: lmer (T60.field ~ CD * MFS * SNC + CD² + MFS² + SNC² + Lat + Lon + (1|Region/Year/Landscape) + (1|Crop type))*

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To test whether crop type had a significant effect on field-level multitrophic diversity, we used a restricted likelihood-ratio test based on simulated values from the finite sample distribution available in the function exactRLRT from package RLRsim. We then compared the estimates and p-values associated with models 9 and 10 to determine whether any effects of crop type influenced our conclusions regarding the effects of crop heterogeneity on multitrophic diversity.

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Although we detected a significant effect of crop type on field-level multitrophic diversity (RLRT = 125.43, p-value < 0.001), adding crop type as a random effect in the model did not change the outcome of model selection or the significance of variables of interest (Table S5.8). This result suggests that variations in the identity of crops sampled do not explain the effects of CD, in combination with SNC, and MFS on multitrophic diversity detected in our study.

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Table S5.10. Comparison of models built at the field level for multitrophic diversity (model 9 – field level, i.e. without sampled crop type as a random effect; model 10 – sampled crop id, i.e. with sampled crop type as a random effect). Parameter listed are those retained in the model selection procedure. Parameter estimates and confidence intervals are based on the model averaging approach. ° p<0.1; * p<0.05; ** p<0.01; *** p<0.001.

	model 9 (field)	model 10 (field) – sampled crop ID
Crop diversity (CD)	0.78 [-0.79 ; 2.36]	0.25 [-2.08 ; 2.58]
Mean field size (MFS)	-3.14 [-6.57 ; 0.28] °	-2.44 [-4.77 ; -0.10] *
Semi-Natural Cover (SNC)	3.14 [-1.12 ; 7.4]	3.79 [0.98 ; 6.60] **
Latitude	0.97 [-3.4 ; 5.33]	
Longitude	3.63 [-1.68 ; 8.93]	1.2 [-4.88 ; 7.28]
CD ²		0.67 [-4.25 ; 5.6]
MFS ²	2.07 [-1.52 ; 5.66]	1.19 [-2.38 ; 4.76]
SNC ²	2.9 [-1.27 ; 7.06]	2.05 [-2.08 ; 6.18]
CD :SNC	1.35 [0.08 ; 2.63] *	1.39 [0.14 ; 2.63] *
MFS :SNC	1.55 [0.09 ; 3.00] *	1.91 [0.47 ; 3.34] **
CD :MFS		0.2 [-1.12 ; 5.56]

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5.6.2. Role of crop heterogeneity in cereal fields

To further assess the role of crop identity, we applied model 9 to the subset of data collected in cereal fields. Indeed, cereal is the most widespread crop type sampled in our dataset and the only one present in all regions. We therefore applied model 6 on 615 fields in 334 landscapes in our 8 regions (after removing the random effect of landscape since most landscape contain only one cereal field). This analysis confirms that decreasing MFS and, when SNC is high enough, increasing CD have positive effects on multitrophic diversity in cereal crop fields (Table S5.11).

Table S5.11. Comparison of models built at the field level for multitrophic diversity (model 9) with the complete dataset and with the cereal subset. Parameter listed are those retained in the model selection procedure. Parameter estimates and confidence intervals are based on the model averaging approach. ° p<0.1; * p<0.05; ** p<0.01; *** p<0.001.

	model 9 (field) – complete dataset	model 9 (field) – cereal subset
Crop diversity (CD)	0.78 [-0.79 ; 2.36]	-2.78 [-8.62 ; 3.06]
Mean field size (MFS)	-3.14 [-6.57 ; 0.28] °	-4.51 [-9.24 ; 0.23] °
Semi-Natural Cover (SNC)	3.14 [-1.12 ; 7.4]	3.16 [0.26 ; 6.06] *
Latitude	0.97 [-3.4 ; 5.33]	
Longitude	3.63 [-1.68 ; 8.93]	2.03 [-0.87 ; 4.94]
MFS ²	2.07 [-1.52 ; 5.66]	3.62 [-0.19 ; 7.43] °
SNC ²	2.9 [-1.27 ; 7.06]	1.49 [-3.09 ; 6.08]
CD :SNC	1.35 [0.08 ; 2.63] *	1.76 [0.17 ; 3.36] *
MFS :SNC	1.55 [0.09 ; 3.00] *	3.31 [1.73 ; 4.9] ***
CD :MFS		0.46 [-1.17 ; 2.09]

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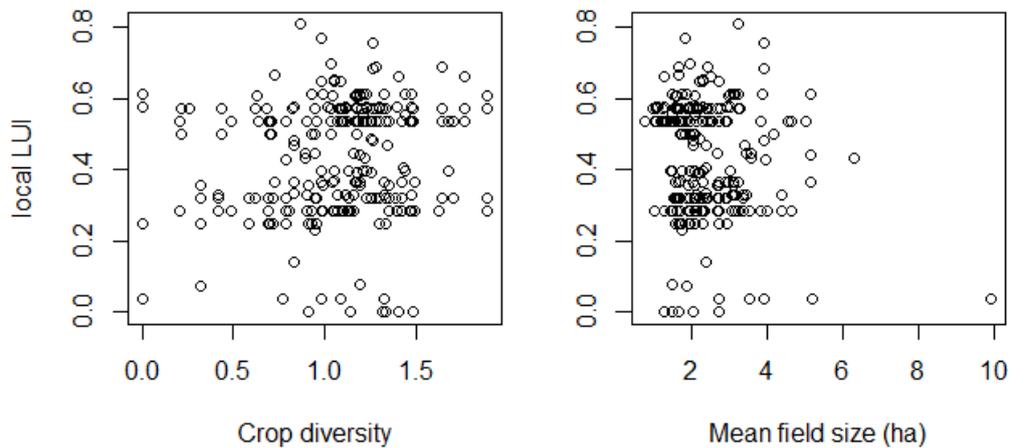
5.6.3. Role of field-level Land-Use Intensity

Land-use intensity may be correlated with crop heterogeneity in some regions. For instance, landscapes with larger mean field sizes may be associated with higher fertilizer inputs (Levers et al. 2016, Roschewitz et al. 2005). Such correlations could hamper our ability to draw conclusion on the effects of crop heterogeneity on multitrophic diversity.

We conducted farmer surveys to collect data on land use intensity of the sampled fields. Information included ploughing (0=no/1=yes), use of fertilizer (0=no/1=yes), frequency of herbicide use (from 0 to 7) and frequency of insecticide use (from 0 to 6) in 324 fields located in 132 landscapes across five regions (Armorique, Camargue, Coteaux, Goettingen and Eastern Ontario). We calculated a local Land-Use Intensity index (local LUI) based on the normalized mean of these four variables (after scaling each variable) following a formula similar to the one developed by Herzog et

1648 al. (2006): $LUI = \frac{1}{4} (\text{scale(ploughing)} + \text{scale(fertilizer)} + \text{scale(herbicide)} + \text{scale(insecticide)})$. This local
 1649 LUI index therefore varies between 0 (low intensity) and 1 (high intensity).

1650 The Pearson correlation between local LUI and crop diversity was weak and not significant
 1651 ($r=0.10$; $p=0.12$). The Pearson correlation between local LUI and mean field size was negative (i.e.
 1652 opposite to expectation; $r= -0.27$; $p<0.001$; Fig. S5.4).
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 1655 **Figure S5.4.** Relationship between the two crop heterogeneity gradients and Land-Use Intensity
 1656 (LUI).

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 1658 We added local LUI to model 10 and compared the outcomes of model 10 and model 11
 1659 using the data subset for which Field LUI data was available.

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 1661 *Model 11: $lmer(T60.field \sim CD * MFS * SNC + CD^2 + MFS^2 + SNC^2 + Lat + Lon + Field\ LUI + (1|$
 1662 *Region/Year/Landscape) + (1|Crop type))**

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 1664 Model selection based on model 11 included almost the same variables as for model 10, plus
 1665 Field LUI, which had a significant negative effect. Parameter estimates for model 10 using the LUI
 1666 data subset differ slightly from parameter estimates due to the fact that more complex interactions
 1667 were included. However, we checked that the overall shape of the relationships do not differ much
 1668 between the model based on the whole dataset and the model based on the LUI dataset. More
 1669 importantly, parameter estimates and significance for other variables of interest remained very
 1670 similar between model 10 and model 11 (Table S5.12). This result suggests that the effects of mean
 1671 field size and crop diversity cannot be explained by variations in field-level land-use intensity. It is
 1672 interesting to note that we observe here a significant negative interaction between crop diversity
 1673 and mean field size which is consistent with the ‘landscape complementation’ hypothesis, i.e. the
 1674 fact that multitrophic diversity benefit more from increasing crop diversity when fields become
 1675 smaller and can be reached more easily. However, the fact that this relationship was not observed in
 1676 other models calls for further investigations.

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 1678 **Table S5.12.** Comparison of models built at the field level for multitrophic diversity with and without
 1679 field-level land use intensity (LUI). Parameter listed are those retained in the model selection
 1680 procedure. Parameter estimates and confidence intervals are based on the model averaging
 1681 approach. ° $p<0.1$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.
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	model 10 (field level LUI subset)	model 11 (field level LUI subset) - LUI
Crop diversity (CD)	18.1 [5.35 ; 20.85] **	16.14 [3.42 ; 28.86] *
Mean field size (MFS)	8.81 [0.31 ; 17.31] *	8.32 [-0.41 ; 17.05] °

Semi-Natural Cover (SNC)	17.69 [6.26 ; 29.12] **	19.11 [7.9 ; 30.33] ***
Latitude	4.38 [0.95 ; 7.82] *	5.91 [1.72 ; 10.09] **
Longitude	2.98 [-0.19 ; 6.15] °	
CD ²	-15.54 [-27.25 ; -3.83] **	-14.25 [-25.88 ; -2.61] *
MFS ²	-12.27 [-21.8 ; -2.7] *	-13.33 [-22.78 ; -3.88] **
SNC ²	-15.76 [-27.97 ; -3.54] *	-17.9 [-29.89 ; -5.91] **
CD :SNC	-4.8 [-8.53 ; -1.06] *	-5.2 [-8.86 ; -1.55] **
MFS :SNC	2.55 [-0.77 ; 5.86]	
CD :MFS	-4.06 [-7.55 ; -0.57] *	-3.8 [-6.71 ; -0.87] *
CD :MFS :SNC	1.6 [-0.99 ; 4.19]	
Field LUI		-2.53 [-4.79 ; -0.26] *

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5.7. Moving window modeling approach for Crop heterogeneity × Semi-natural cover interaction

We used a moving window modeling approach (Humpries et al. 2010; Berdugo et al. 2018) to identify potential discontinuities in the response of multitrophic diversity measured at the landscape level (T60.landscape) to crop diversity and mean field size along the gradient of semi-natural cover. To do so, we ordered all landscapes (n = 435) along the gradient of semi-natural cover (%) and selected the first 75 landscapes with the lowest semi-natural cover. Using this subset, we ran the model obtained from the averaging approach applied to model 1 (Fig. 2A main text) after excluding semi natural cover and its interactions with CD and MFS, such as:

*Model 12: lmer (T60.landscape ~ CD*MFS + MFS² + CropNb + Lat + Lon + (1 | Region/Year))*

We then extracted and stored the model coefficient for crop diversity (CD), mean field size (MFS) and the confidence intervals (CIs). We then removed the landscape with the lowest value of semi-natural cover from the subset of 75 landscapes, added the landscape scoring the next higher value, ran model 12 and extracted model coefficients and CIs. We repeated this loop as many times as landscapes remained along the entire gradient of semi-natural cover (n = 286 subsets, see R code below). We saved all coefficients and confident intervals for each step and plotted them against the gradient of semi-natural cover (Fig. S5.5).

Consistently with our multiple regression analyses (Fig. 2A in main text), this moving window analysis showed that the effect of crop diversity and mean field size on multitrophic diversity changes along the gradient of semi-natural cover (Fig. S5.5 A and B). The effect of crop diversity is positive for high values of semi-natural cover, neutral as semi-natural cover decreases and negative for the low values of semi-natural cover. The effect of mean field size is neutral for the high values of semi-natural cover and negative for low values of semi-natural cover.

However, this analysis reveals that changes in the effect of crop diversity and mean field size on multitrophic diversity are not smooth but instead show abrupt transitions when semi-natural cover decreases. For crop diversity, there is an abrupt change at 11.2% of semi-natural cover where the effect of crop diversity shifts abruptly from positive to neutral and one at 4.5% where the effect of crop diversity shifts from neutral to negative. For mean field size, there is one abrupt change at 8% where the effect of mean field size shifts abruptly from neutral to negative. This analysis allows identifying three thresholds that can be used to guide recommendations on how to manage the three main components of agricultural landscape heterogeneity, namely crop diversity, mean field size and the amount of semi-natural cover (see main text for more details).

R Code for the Moving Window Analysis (the code provided only concerns crop diversity)

```

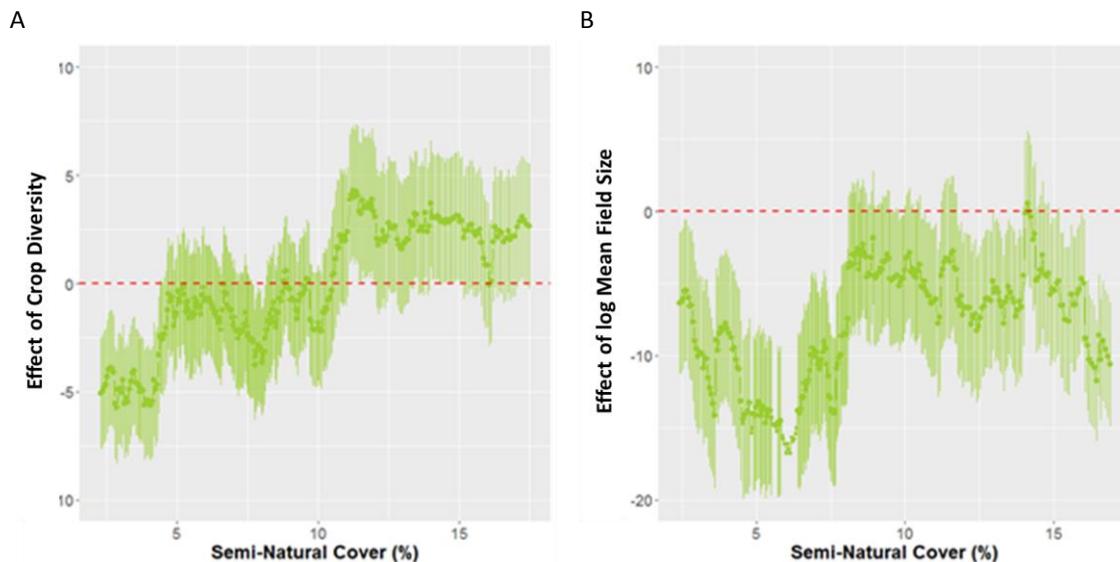
1724 ##### moving window function
1725 WindowSKR <- function(df,Factor,X,Y,formul,n=10){
1726   myvars<-c(Factor,X,Y)
1727   dftemp = df[myvars]
1728   dftemp = dftemp[order(dftemp[Factor]),]
1729   tt=length(unlist(dftemp[Factor]))-n
1730   i = 1
1731   mdl <- lmer(data = dftemp, formula = formul)
1732   res<- matrix(data = NA,nrow = 1,ncol = length(fixef(mdl))+1)
1733   ci<-res
1734   library(lme4)
1735   while(tt>n){
1736     dfi <- dftemp[i:(i+n),]
1737     Fact <- mean(unlist(dfi[Factor]))
1738     mdl <- lmer(data = dfi, formula = formul, na.action = na.fail,REML ="TRUE")
1739     #dist<- mean(unlist(dfi[X]))+1-mean(unlist(dfi[Y]))
1740     res <- rbind(res,c(Fact,fixef(mdl)))
1741     cii <- (abs(confint(mdl)[-c(1,2),1]-confint(mdl)[-c(1,2),2]))/2
1742     ci<-rbind(ci,c(Fact,cii))
1743     tt=tt-1
1744     i=i+1
1745   }
1746   res<- as.data.frame(res)
1747   ci<-as.data.frame(ci)
1748   colnames(res)<-c("MWfactor",names(fixef(mdl)))
1749   colnames(ci)<-c("MWfactor",names(fixef(mdl)))
1750   RES<-list(res=res,ci=ci)
1751   return(RES)
1752 }
1753
1754 ##### uploading libraries
1755 library(jsonlite)
1756 library(ggplot2)
1757 library(tidyr)
1758 library(boot)
1759 library(lme4)
1760
1761 ##### running moving window analysis
1762 formul<-T60.landscape~ Crop_SHDI+Crop_MFS + sampled.crop.nb + MFS2 + Lon + Lat + (1|Region/Year) -1
1763 RES <- WindowSKR(df,"Seminat_Cover",c("Crop_SHDI","MFS2","Crop_MFS", "Seminat_Cover",
1764 "sampled.crop.nb", "Region", "Year", "Lon", "Lat"),"T60.landscape",formul,n=75)
1765
1766 ##### plotting results of the moving window analysis
1767 dfres=data.frame(MWfactor<-RES$res$MWfactor, Effect<-RES$res$Crop_SHDI, CI<-RES$ci$Crop_SHDI)
1768 limits <- aes(ymax = Effect + CI, ymin=Effect - CI)
1769 p1<-ggplot(data = dfres,aes(x = MWfactor,y = Effect), ylim = c(1,4))+
1770   geom_line(col = "olivedrab3")+
1771   geom_point(col = "olivedrab3")+
1772   geom_pointrange(limits,col = "olivedrab3")+
1773   xlab("Semi-Natural Cover (%)")+

```

```

1774 ylab("Effect of Crop Diversity")
1775 p1 + theme(axis.text=element_text(size=14), axis.title.x = element_text(size=18, face="bold"), axis.title.y =
1776 element_text(size=18, face="bold"))
1777
1778

```



1779 **Figure S5.5.** Effect of crop diversity (A) and mean field size (B) on multitrophic diversity for different levels of
1780 semi-natural cover. Parameter estimates and confidence intervals are based on a moving window analysis (see
1781 detailed description in SI5). The red line indicates a null effect. Each dot and CI correspond to the estimate
1782 values of CD or MFS for the average semi-natural cover of a given window along the semi-natural cover
1783 gradient. Due to the low number of landscapes with semi-natural cover >17.5% (Table S4.1), we only represent
1784 the gradient between 0 and 17.5% of semi-natural cover on these figures.
1785
1786

1787
1788 **References**

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1801