Mixed effects of ecological intensification on natural pest control providers: a short-term study for biotic homogenization in winter wheat fields

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Agricultural intensification is one of the major drivers of biotic homogenization and has multiple levels ranging from within-field management intensity to landscape-scale simplification. The enhancement of invertebrate assemblages by establishing new, semi-natural habitats, such as set-aside fields can improve biological pest control in adjacent crops, and mitigate the adverse effect of biotic homogenization. In this study we aimed to examine the effects of ecological intensification in winter wheat fields in Hungary. We tested how pests and their natural enemies were affected at different spatial scales by landscape composition (proportion of semi-natural habitats in the surrounding matrix), configuration (presence of adjacent set-aside fields), and local field management practices, such as fertilizer (NPK) applications without applying insecticides. We demonstrated that at the local scale, decreased fertilizer usage had no direct effect either on pests or their natural enemies. Higher landscape complexity and adjacent semi-natural habitats seem to be the major drivers of decreasing aphid abundance, suggesting that these enhanced the predatory insect assemblages. Additionally, the high yield in plots with no adjacent set-aside fields suggests that intensive management can compensate for the lower yields on the extensive plots. Our results demonstrated that although complexity at the landscape scale was crucial for maintaining invertebrate assemblages, divergence in their response to pests and pathogens could also be explained by different dispersal abilities. Although the landscape attributes acted as dispersal filters in the organization of pest and pathogen assemblages in croplands, the presence of set-aside fields negatively influenced aphid abundance due to their between-field isolation effect.

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3 fields

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25   **Abstract**

26   Agricultural intensification is one of the major drivers of biotic homogenization and has multiple

27   levels ranging from within-field management intensity to landscape-scale simplification. The

28   enhancement of invertebrate assemblages by establishing new, semi-natural habitats, such as set-

29   aside fields can improve biological pest control in adjacent crops, and mitigate the adverse effect

30   of biotic homogenization. In this study we aimed to examine the effects of ecological

31   intensification in winter wheat fields in Hungary. We tested how pests and their natural enemies

32   were affected at different spatial scales by landscape composition (proportion of semi-natural

33   habitats in the surrounding matrix), configuration (presence of adjacent set-aside fields), and

34   local field management practices, such as fertilizer (NPK) applications without applying

35   insecticides. We demonstrated that at the local scale, decreased fertilizer usage had no direct

36   effect either on pests or their natural enemies. Higher landscape complexity and adjacent semi-

37   natural habitats seem to be the major drivers of decreasing aphid abundance, suggesting that these

38   enhanced the predatory insect assemblages. Additionally, the high yield in plots with no adjacent

39   set-aside fields suggests that intensive management can compensate for the lower yields on the

40   extensive plots. Our results demonstrated that although complexity at the landscape scale was

41   crucial for maintaining invertebrate assemblages, divergence in their response to pests and

42   pathogens could also be explained by different dispersal abilities. Although the landscape

43   attributes acted as dispersal filters in the organization of pest and pathogen assemblages in

44   croplands, the presence of set-aside fields negatively influenced aphid abundance due to their

45   between-field isolation effect.

46

47   **Keywords:** aphids; ecosystem services; inorganic fertilizer; pathogens; set-aside field

48

49

Introduction

50

51   Landscape simplification has been suspected to influence the local patterns of

52 species richness and abundance, because of the reduced capacity to support large species-pools,

53 and the lack of opportunity for spill-over between different habitats (Tscharntke et al., 2012, Karp

54 et al., 2018, Dainese et al. 2019). Nevertheless, the effects of agricultural intensification

55 (characterized by intensive land use and the vast application of agrochemicals) at different spatial

56 scales have only been partially analyzed (Hendrickx et al., 2007; Gámez-Virués et al., 2015;

57 Gagic et al., 2017). Agricultural intensification may also serve as an ecological filter, simplifying

58 entire communities through the process of biotic homogenization, as well as decreasing the

59 diversity and resilience against the disturbance caused by farm management (Olden et al., 2004;

60 Gámez-Virués et al., 2015; Tscharntke et al., 2016). The simplified arthropod communities might

61 be restricted in their functions, and may result in the deterioration of ecosystem services (Yachi

62 & Loreau, 1999, Woodcock et al. 2016). Although the environmental filtering of the local habitats

63 and landscape composition may act as a driver for biotic homogenization, their effects on the

64 assemblages of pests and their natural enemies has been rarely explored.

65   Insect pollinators, natural enemies, and soil decomposers are key factors for

66 production in the various economically important crop systems (Bartomeus, Gagic & Bommarco,

67 2015; Klein et al., 2015; Tamburini et al., 2016). These groups provide regulatory ecosystem

68 services (ES), often influenced by field management, landscape composition and configuration

69 (Karp et al., 2018). There is an emerging interest in how agricultural management and external

70 inputs can be combined with, or potentially replaced by ESs to enhance yields (Bommarco,

71 Kleijn & Potts, 2013; Klein et al., 2015; Marini et al., 2015; Kleijn et al. 2019). Ecological

72 intensification (EI) has been proposed with the aim to exploit the power of ESs in order to sustain

73 agricultural production, while minimizing the adverse effects on the environment, such as the loss

74 of biodiversity or landscape simplification (Kleijn et al., 2019). Although growing evidence

75   suggests that ecologically intensified farming can safeguard food production and mitigate its

76   adverse effects on the natural environment, the conscious use of ES providers (natural enemies,

77   pollinators, decomposers, etc.) is still scarce (Bommarco, Kleijn & Potts, 2013; Martin,

78   Reineking, Seo & Steffan-Dewenter, 2015). For instance, Tamburini et al. (2016) proved that

79   biological pest regulation was influenced by soil management, suggesting that conservation

80   tillage enhances soil fertility and natural pest control. Moreover, geographical bias exists: most of

81   the studies on the relationship between farmland diversity (as a proxy for available ESs) and

82   agricultural management have emerged from Western Europe (Tryjanowski et al., 2011; Sutcliffe

83   et al., 2015) and North America (Kleijn et al., 2019).

84   In this study, we tested whether the enhancement of beneficial invertebrate

85   assemblages, as pest control providers could contribute to the improvement of crop yields

86   through reduced level of management intensity. We also looked for clues whether the number of

87   newly established, semi-natural habitats adjacent to winter wheat fields could act as proxies for

88   EI. We also tested whether fertilizers, as a key part of intensified crop management, interacted

89   with landscape composition and configuration on selected pathogens, aphids and their natural

90   enemies. We hypothesized that (i) a higher proportion of semi-natural habitats in the landscape

91   can mitigate the negative effects of local (intensive) field management practices on the within-

92   field abundance of natural enemies. Thus, enhanced connectivity between the habitat patches

93   might lead to more natural enemies at the landscape level, and (ii) at the between-field scale,

94   winter wheat fields with adjacent set-aside fields would have a higher abundance of natural

95   enemies and enhanced natural pest control. At the plot level, we assumed that (iii) intensive

96   inorganic fertilizer use in poor soils (acidic soil pH with low soil organic content) would enhance

97   wheat yields, as well as the abundance of pathogens and aphids; while fertilizer usage in good

98   soils (i.e., high soil organic content, neutral pH) would not have such an effect.

99

100   **Material and methods**

101   *Experimental area*

102   Our study was conducted in the Heves Plain High Nature Value Area in North-

103   Eastern Hungary. This region is one of the major target areas of agri-environmental schemes in

104   Hungary (Kovács-Hostyánszki, Batáry & Báldi 2011; Kovács-Hostyánszki & Báldi 2012). The

105   proportion of croplands in this region was 70%, the major crops being winter wheat, maize, as

106   well as spring- and winter barley. Other major but less frequently sown crops were oilseed rape,

107   sugar beet and sunflower. We selected 14 experimental winter wheat fields of 5–10 ha (geometric

108   mean =7.071 ha, S.D.=3.53 ha). Seven of these had an adjacent, newly established (1 to 3 years

109   old) set-aside field of sizes between 1.98 to 5.43 ha (geometric mean =4.102 ha, S.D.=± 1.65 ha),

110   while the others, without any adjacent set-aside field, served as controls. The distance between

111   the studied wheat fields was 1.54 - 10.84 km. The set-aside fields were sown by a seed-mixture,

112   which included one leguminous (i.e., *Medicago sativa*) and two grass species (i.e., *Lolium* spp.,

113   *Festuca* spp.). During the maximum time of the 3-year set-aside management period, the use of

114   agrochemicals was prohibited, and the fields were mown once a year in the second half of June

115   (Kovács-Hostyánszki, Batáry & Báldi 2011). The owners of these set-aside fields took part in the

116   Hungarian Agri-Environmental Programme (HAEP-NHRDP 2007–13), in which the primary

117   goal was to improve soil fertility and water retention, as well as to increase farmland biodiversity.

118   In 2014, we assigned an experimental plot of 45 × 20 m in each of the selected

119   winter wheat field adjacent to the field margin (Fig. 1a). In the wheat fields with adjacent set-

120   aside fields, the plot was at the edge towards the set-aside field. The farmers were asked to avoid

121   applying fertilizers or insecticides within the experimental plots while maintaining all other

122   conventional management practices. To assess the impact of fertilizer application and to avoid

123   any interference between treatments, these areas were subdivided into two plots of 20 × 20 m,

124   with a 5 m separation strip between them. One plot was treated with an NPK fertilizer at the usual

125   rate of 95 kg N/ha in mid-April 2014, while the other plot received no fertilizer input (fertilizer

126   control, Fig. 1a).

127

128   *Soil characterization*

129   We collected 15 cm soil cover to assess the soil organic content (SOC, a proxy for

130   soil fertility) and pH. A total of 15 samples were taken per fertilizer control plots at the 10+ stage

131   (BBCH scale, Zadoks et al., 1974) of the wheat plants in mid-March and were stored at 4° C.

132   Prior to analysis, samples from each plot were sieved (at 4 mm mesh size) and blended.

133   Subsequent soil analyses were conducted according to the Hungarian certifications (no. 08-0452

134   and 08-0206-2) and the method described by Mason (1983).

135

136   *Landscape attributes*

137   The landscape composition was calculated in a circle with 1000 m-radius around

138   each studied field. The proportion of arable fields, semi-natural habitats (semi-natural grasslands,

139   semi-natural forests, tree lines, hedges and shrubs), urban areas and water bodies were measured

140   using a GIS database (QGIS Development Team, 2018). We considered landscapes with > 20%

141   semi-natural habitats as structurally complex, while landscapes with <20% of such habitats were

142   classified as simple (Batáry et al., 2011; Tscharntke, Batáry & Dormann, 2011). The

143   presence/absence of set-aside fields adjacent to a study plot indirectly measures the spatial

144   configuration (i.e., frequency of semi-natural habitats in the landscape) of the studied land use

145   categories (Fahrig et al., 2011).

146

147   *Arthropod and pathogen surveys*

148   The abundance of aphids, their natural enemies and wheat pathogens was assessed

149   by visual plant surveys in each plot along two parallel transects perpendicular to the margin, 5 m

150 from each other at 5, 10 and 20 m from the edge of the wheat fields adjacent to the set-aside field,

151 which were towards the habitat core. We randomly selected 17 wheat tillers per transect per

152 distance (17 ×2 × 3 = 102 tillers per plot, Fig. 1b), and on each of these, we counted the number

153 of grain aphids (mostly *Sitobion avenae,* Hemiptera: Aphidoidea), coccinellid adults and larvae

154 (Coleoptera: Coccinellidae), syrphid larvae (Diptera: Syrphoidea), chrysopid larvae (Neuroptera:

155 Chrysophidae), and the number of parasitized aphids (including mummies). We also visually

156 assessed the major pathogens, including leaf spots (*Septoria* spp., *Fusarium* spp.), mildew and

157 rust (*Puccinia* spp.) on the leaves. Plant surveys were conducted on three occasions in April

158 (stem elongation stage; BBCH 35), May (head-forming stage; BBCH 50) and June (flowering

159 stage; BBCH 60).

160   To monitor the activity density (a proxy for abundance from pitfall trap data,

161 hereafter referred as 'abundance') of the surface-active natural enemies, four pitfall traps were

162 installed along the transects (Fig. 1b) in each experimental (i.e,. fertilized and control) plot and

163 operated for two weeks in late May - early June. The traps consisted of plastic cups of ~114 mm

164 diameter, each of which filled with approximately 250 ml of a 50% propylene glycol solution

165 saturated with NaCl and a drop of odorless detergent to reduce the surface tension. A green

166 plastic roof protected the traps from litter and rain. The pitfall traps were emptied after 14 days,

167 the catch was sorted in the laboratory, and the abundance of adult ground beetles and cursorial

168 spiders (Lycosidae) was calculated.

169

170 *Estimating yield*

171   In June, all experimental plots were hand-harvested. Two sub-samples of 0.58 ×

172 0.58 m area were taken at each distance (5, 10 and 20 m), resulting in a harvest sample of 1 m^2 in

173 total. Harvested ears were transported in cotton bags and dried at 24° C for 48 h in a climate

174 chamber under 10% RH. After threshing, we measured the total fresh grain mass per replicate

175   batch, as well as fresh and dry mass of sub-samples in order to calculate the total grain yield (g/

176   m^2) (standardized to a moisture content of 14%); the grain and the ear mass were used for further

177   analyses.

178

179   *Statistical analyses*

180   We used linear mixed models to test the responses of pests (aphid abundance),

181   pathogens (prevalence of leaf spots expressed as percentage), natural enemies (abundance of

182   ground beetles and spiders) and winter wheat yields (estimated as mass of wheat- ear and grain)

183   to soil properties, nitrogen use, landscape complexity and configuration. To achieve a normal

184   distribution of the residuals, all response variables were square-root transformed. We created sets

185   of single-argument models on each response variable, to avoid colinearity and maximize the

186   predictive power of explanatory variables, only one explanatory variable was considered in each

187   model (Burnham & Anderson, 2002). As for explanatory variables, we included soil properties

188   including pH (continuous variable) and SOC (continuous variable), nitrogen treatment

189   (categorical variable with two levels: fertilizer applied/not applied), presence of adjacent set-

190   aside field (categorical variable with two levels: with/without bordering set-aside field), or

191   landscape complexity (categorical variable with two levels: simple/complex). In all models, the

192   farm ID (nominal variable) was used as a random effect. For these aforementioned models we

193   used the function 'lme' from the 'nlme' package (Pinheiro et al., 2017). Afterwards, each set of

194   models was tested to select the best ones based on the Akaike Information Criterion (AICc)

195   corrected for small samples sizes (Burnham & Anderson, 2002) using the model.sel function

196   from the 'MuMIn' package (Bartoń, 2016). When ΔAICc > 2, the 'best approximating' model

197   was selected as the most parsimonious explanation (see Table 1 for details). When more than one

198   model had ΔAICc < 2, we applied a model averaging approach for the uncertainty in model

199   selection and obtained robust parameter estimates (Grueber et al., 2011). During model

200   averaging, we built all possible models with the given explanatory variables and parameter

201   estimates of the best models (ΔAICc < 2), which were fully averaged with the models' AICc

202   weights. We used the dredge and model.avg functions from the 'MuMIn' package for model

203   averaging. All the analyses were compiled in R 3.4.1 (R Core Team, 2019). The datasets collected

204   on different sampling occasions were pooled for analyses. For all analyses, the alpha was set to

205   0.05.

206

207   **Results**

208   *Pests and pathogens*

209   The presence of adjacent set-aside fields significantly affected aphid abundance.

210   There were significantly more aphids in winter wheat fields without adjacent set-aside fields than

211   in those with set-aside fields (Table 2, Fig 2a). Neither soil properties, nor nitrogen use or

212   landscape complexity affected aphid abundance. We did not find any significant effects of within-

213   and between-field factors on the prevalence of aphids. The prevalence of leaf spots was higher in

214   complex than in simple landscapes (Fig 2b).

215

216   *Natural enemies*

217   Our results did not indicate significant impact on the abundance of the two

218   studied groups of ground-dwelling predators by any studied factors (Table 2, Fig. 3). However,

219   the model selection procedure revealed that individual models, including pH and fertilizer

220   treatments, were the two most parsimonious ones to describe the changes in carabid abundance,

221   while those featuring landscape complexity and the presence of adjacent set-aside fields, as well

222   as SOC and fertilizer treatments, were the best models for describing the changes in spider

223   abundance (Table 1). In addition, soil pH had a marginally positive effect on the abundance of

224   ground beetles, suggesting that, on average, slightly more beetles were present in the soil with

225   neutral pH.

226

227   *Yield estimations*

228   Ear and grain mass were significantly higher in fields without adjacent set-aside

229   fields (Table 2, Fig 2c, 2d) but no other variable had an impact on yield.

230

231   **Discussion**

232   We compared the effects of EI on the relationships between pests and their natural

233   enemies at different spatial scales, from within- to between-field differences and up to landscape

234   scale effects. We found that adjacent set-aside fields and landscape complexity seemed to be the

235   drivers of the reduction in aphid abundance and the prevalence of pathogenic fungi. However,

236   fertilizer use had no direct effect either on pests or their natural enemies.

237

238   *Landscape influence on pests and pathogens*

239   Agricultural landscapes are not static and may influence disease dynamics not

240   only through its structure but also through its own dynamics (Plantegenest, Le May & Fabre,

241   2007). We found that the landscape configuration and complexity were key factors in the

242   distribution of pests and pathogens, but the distribution of pathogenic fungi did not support the

243   hypothesis that a higher proportion of semi-natural habitats in the landscape can mitigate the

244   negative effects of local (intensive) field management practices on the within-field abundance of

245   natural enemies, since complex landscapes did not restrict the distribution of pathogens. Although

246   a previous study (Pfender et al., 2006) using a complex air pollution models (CALPUFF)

247   demonstrated that the spores of pathogenic fungi had high deposition within a radius of 1–2 km

248   around their source, the complexity of the landscape could actually lead to a locally higher

249   infection rate due to a decreased air transfer distance of about 0.4 km (Plantegenest, Le May &

250   Fabre, 2007). This finding was similar to our results on the prevalence of leaf spots, which was

251   higher in the plots within the complex landscape. The decreased infection in simple agricultural

252   landscapes could also be explained by the more effective chemical treatments (Plantegenest, Le

253   May & Fabre, 2007; Gagic et al., 2017). We also demonstrated that the studied ground-dwelling

254   predators seemed to be unaffected by the landscape constrains, leaving our hypothesis (i)

255   unsupported. With regard to carabid beetles, in contrast to a previous study (Cole et al., 2002) we

256   found that local species diversity in agricultural fields did not differ significantly when compared

257   to semi-natural areas, owing to the high turnover of the typical agrobiont species. Our local

258   spider assemblages were enhanced in the patches surrounded by a larger percentage of non-crop

259   habitats, agreeing with earlier results by Clough et al., (2005) and Hendrickx et al. (2007).

260   Additionally, the local communities in landscapes consisting of small and disconnected patches

261   were characterized by a species composition with low beta-diversity. This homogenization caused

262   by agricultural intensification may suggest that local assemblages are becoming more

263   unsaturated, most probably because of the loss of specialist – and typically less competitive –

264   species with low dispersal ability, such as many ground-dwelling predators (Clough et al., 2005,

265   Hendrickx et al., 2007). In addition, highly mobile species could mask the effect of spatial

266   heterogeneity between habitats, as demonstrated on orthopterans by Marini et al. (2011).

267

268   *The beta diversity of natural enemies is masked by their mobility*

269   We observed that less grain aphids were on plots that had adjacent set-aside

270   habitats, while the natural enemies seemed unaffected, thus our hypothesis (ii) was just partially

271   supported. This could be explained by the spillover of natural enemies into crop fields, resulting

272   in better pest control (Woodcock et al., 2016). Any increase in aphid population growth, as well

273   as any increase in aphid suppression with an increase in landscape complexity, could be

274   explained by the higher availability of alternative resources and overwintering habitats in the

275   semi-natural habitats around crop fields, benefiting both pests and their natural enemies (Martin

276   et al., 2015; Karp et al., 2019). Additionally, the low abundance of aphids in the plots next to set-

277   aside fields suggested that EI is also characterized by the contribution of other natural enemy

278   groups to pest control (e.g., parasitoid wasps; Martin et al., 2015) or the isolation effect by the

279   adjacent non-crop areas (Dainese et al., 2019; Karp et al., 2019).

280   We observed no effect of the presence of an adjacent set-aside field on the

281   abundance of natural enemies. The available evidence (Hendrickx et al., 2007) suggests that the

282   more specialized species (even natural enemies) abandon the isolated habitat patches that,

283   consequently, contain only a few generalist species of high dispersal ability. The lack of response

284   in two groups of natural enemies at the within-field scale might suggest that the intensive,

285   asymmetric species flows (or spillovers) between the fields during the ripening phase of winter

286   wheat masked eventual differences in habitat utilization between croplands and the semi-natural

287   habitats (*sensu lato* Marini et al., 2011).

288

289   *Yields: conditions within intensive fields are connected to local land-use traditions*

290   Although we demonstrated no effect of fertilization on the abundance of pests,

291   pathogens or their natural enemies, we found that the grain yield was higher in plots without

292   adjacent set-aside than with them. In addition, the yield remained unaffected by soil pH or SOC.

293   These results partially supported our hypothesis (iii), pointing to below- and above-ground ESs.

294   At the below ground, the unaffected yield by soil parameters might be caused by the increased

295   nitrogen loss rate in calcareous soils and the less efficient N utilization in the soil with intensive

296   fertilizer application (Ju et al., 2009). A good quality topsoil with high SOC levels and optimal

297   pH supports a healthy soil fauna (Scheu, 2001). A previous study by Petterson et al. (2007)

298   revealed that higher abundance of grain aphids in fields with high SOC could be explained by

299   their sensitivity to any changes in plant quality. Above ground, the observed lack of effect of

300   fertilizer use on natural enemies, such as spiders and carabids, might imply that high SOC levels

301   and optimal pH could support the soil fauna, which provides sufficient food for these groups to

302   successfully resist management related disturbances. This may lie behind the marginally positive

303   effect of pH on carabid abundance.

304   The fact that we did not detect any direct effect of the fertilizer on crop yield

305   might lead to the conclusion that high soil fertility itself was more important than the external

306   inputs. The lack of a relationship between the yield and any soil parameter such as pH and SOC

307   could also be explained by the fact that while the best soils were farmed by intensive methods,

308   the owners used their less fertile land as set-aside fields. We also found high yields in fields

309   without adjacent set-aside fields. This could be explained by between-site variability in soil

310   properties, which were independent of the proportion of arable land in the landscape, and being

311   masked by intensive management practices (Williams & Hedlund, 2013; Bartomeus Gagic &

312   Bommarco 2015; Gagic et al., 2017). Crop yield is influenced by a combination of biotic and

313   abiotic factors. A better understanding of the interactions between above- and below-ground

314   processes and ESs might ensure high crop yields, but this also requires the investigation of how

315   they co-vary within and between crop fields (Gagic et al., 2017; Tamburini et al., 2016).

316

317

318   ***Conclusions***

319   In conclusion, landscape features such as the presence of set-aside areas were the most important

320   factors in determining the abundance of aphids in our studied cereal fields. We found that the lack

321   of fertilization is not directly beneficial for spiders or ground beetles, suggesting that such

322   extensive farming might not boost these natural enemies, due to the probability of increased

323   between-field isolation caused by high compositional diversity at a landscape scale (Hendrickx et

324   al., 2007; Martin et al., 2015; Tscharntke et al., 2016). Furthermore, our study focused on near-

325 final ripening phase of the winter wheat, when the activity of natural enemies was the highest in

326 the season, resulting in an equilibrium (equal abundance between croplands and adjacent set-

327 aside fields) in habitat use between croplands, field margins and the set-aside fields (Tscharntke

328 et al., 2012; 2016). Therefore, conserving and enhancing the landscape diversity appears to be the

329 key intervention to optimize the interaction between pests and their natural enemies in this

330 agroecosystem. Our short-term study provided only a snapshot of the complex dynamics of

331 agroecosystems; thus, the detected asymmetric species flows might have masked the differences

332 in habitat utilization by natural enemies. Moreover, our demonstrative results underline the fact

333 that agricultural practices can interfere with the abundance of natural enemies. Several landscape

334 management practices may decrease the abundance of natural enemies and therefore the level of

335 natural pest control. Hence, it is important to utilize evidence-based practices, which may include

336 the reduction in chemical use, and promote natural enemies, as well as pest-specific measures to

337 prevent the expansion of pest populations. Moreover, our results prompted us to conclude that

338 management intensification at the within-field scale was still capable of compensating the yield

339 gap caused by extensive management practices at the between-field scale.

340

341

342 **Acknowledgements**

343   We thank all the farmers who allowed us to work on their land, László Tóth of the

344 Bükk National Park Directorate for his help in the selection of the field sites as well as providing

345 help during the study, Dorottya Molnár for field assistance, and Gábor Lövei for linguistic

346 revision. This study was funded by the EU FP7-project, LIBERATION (Linking farmland

347 Biodiversity to Ecosystem services for effective ecological intensification; project no. 311781)

348 and the MTA Lendület Program. The analysis and writing of the paper was supported by the

349 GINOP–2.3.2–15–2016–00019 project.

350

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Summary of the model selection for each group.

Estimations are based on the calculated AICc value of the models, serving as the weight of evidence in favour of the different models. Most parsimonious models (delta < 2) are marked in bold.

Group	models	df	logLik	AICc	delta	weight
Pests and pathogens						
Aphids	**set-aside**	**4**	**-825.814**	**1659.7**	**0.00**	**0.735**
	pH	4	-827.027	1662.2	2.43	0.218
	SOC	4	-829.284	1666.7	6.94	0.023
	landscape	4	-829.868	1667.8	8.11	0.013
	nitrogen	4	-830.014	1668.1	8.40	0.011
Leaf spots	**landscape**	**4**	**-573.825**	**1155.8**	**0.00**	**0.728**
	set-aside	4	-576.116	1160.3	4.58	0.074
	pH	4	-576.166	1160.4	4.68	0.070
	SOC	4	-576.217	1160.5	4.78	0.067
	nitrogen	4	-576.287	1160.7	4.92	0.062
Natural enemies						
Ground beetles	**pH**	**4**	**-286.264**	**580.9**	**0.00**	**0.422**
	nitrogen	**4**	**-286.910**	**582.2**	**1.29**	**0.221**
	set-aside	4	-287.467	583.3	2.41	0.127
	landscape	4	-287.555	583.5	2.58	0.116
	SOC	4	-287.578	583.6	2.63	0.113
Spiders	**landscape**	**4**	**-237.894**	**484.2**	**0.00**	**0.392**
	SOC	**4**	**-238.766**	**485.9**	**1.74**	**0.164**
	set-aside	**4**	**-238.799**	**486.0**	**1.81**	**0.159**
	nitrogen	**4**	**-238.877**	**486.2**	**1.97**	**0.147**
	pH	4	-238.937	486.3	2.08	0.138
Yield						
Ear mass	**set-aside**	**4**	**-221.817**	**452.1**	**0.00**	**> 0.999**
	SOC	4	-249.092	506.6	54.55	< 0.001
	pH	4	-250.217	508.9	56.80	< 0.001
	nitrogen	4	-253.255	514.9	62.88	< 0.001
	landscape	4	-253.528	515.5	63.42	< 0.001
Grain mass	**set-aside**	**4**	**-208.626**	**425.7**	**0.00**	**> 0.999**
	SOC	4	-236.602	481.6	55.95	< 0.001
	pH	4	-237.652	483.7	58.05	< 0.001
	nitrogen	4	-240.399	489.2	63.55	< 0.001
	landscape	4	-240.777	490.0	64.30	< 0.001

Summary of the best models.

Coefficient and z values correspond to average model, while estimated (beta), t values and SD (random) are for the best models. Significant effects are in bold and directions of significant relationships (positive or negative) are designated by up and down arrows respectively. Marginal trends are underlined. Models' explanatory power tested by R^2 values and AICc.

Group	Best models	Variables	Coefficient/ estimated	SE	df	Z/t	p		SD (random)	marginal R²/Fixed	conditional R²/Random	AICc
Pests and pathogens												
Aphids	Set-aside	intercept	2.219	0.273	378	8.120	< 0.001		0.872	0.113	0.276	1659.63
		set-aside (with)	**-1.464**	**0.448**	**19**	**-3.267**	**0.004**	↓				
Leaf spots	Landscape	intercept	0.762	0.147	361	5.195	< 0.001		0.493	0.059	0.232	1155.65
		landscape (simple)	**-0.599**	**0.213**	**361**	**-2.809**	**0.005**	↓				
Natural enemies												
Ground beetles	Average	(intercept)	1.374	4.654		0.294	0.769			0.073	0.230	580.93
		pH	1.211	0.665		1.706	0.088					
		nitrogen (yes)	-0.881	0.725		1.198	0.231					
Spiders	Average	(intercept)	3.872	0.573		6.673	< 0.001			0.015	0.098	484.16
		landscape (simple)	-0.800	0.551		1.360	0.174					
		SOC	-0.350	0.569		0.576	0.564					
		set-aside (with)	0.276	0.510		0.507	0.612					
Yield												
Ear mass	Set-aside	intercept	17.531	0.589	78	29.759	< 0.001		2.140	0.597	0.820	451.61
		set-aside (with)	**-7.034**	**0.715**	**78**	**-9.832**	**< 0.001**	↓				
Grain mass	Set-aside	intercept	15.127	0.485	78	31.166	< 0.001		1.716	0.619	0.810	425.25
		set-aside (with)	**-6.202**	**0.615**	**78**	**-10.075**	**< 0.001**	↓				

Figure 1

The experimental plots (grey squares) were established next to the field margin.

The F+ (fertilizer added) designate fertilized subplots, while the F- (no fertilizer added) is for the control ones. Within an experimental plot (b), the locations of inventory transects are indicated by white rectangles and subplots for wheat harvesting with black ones.
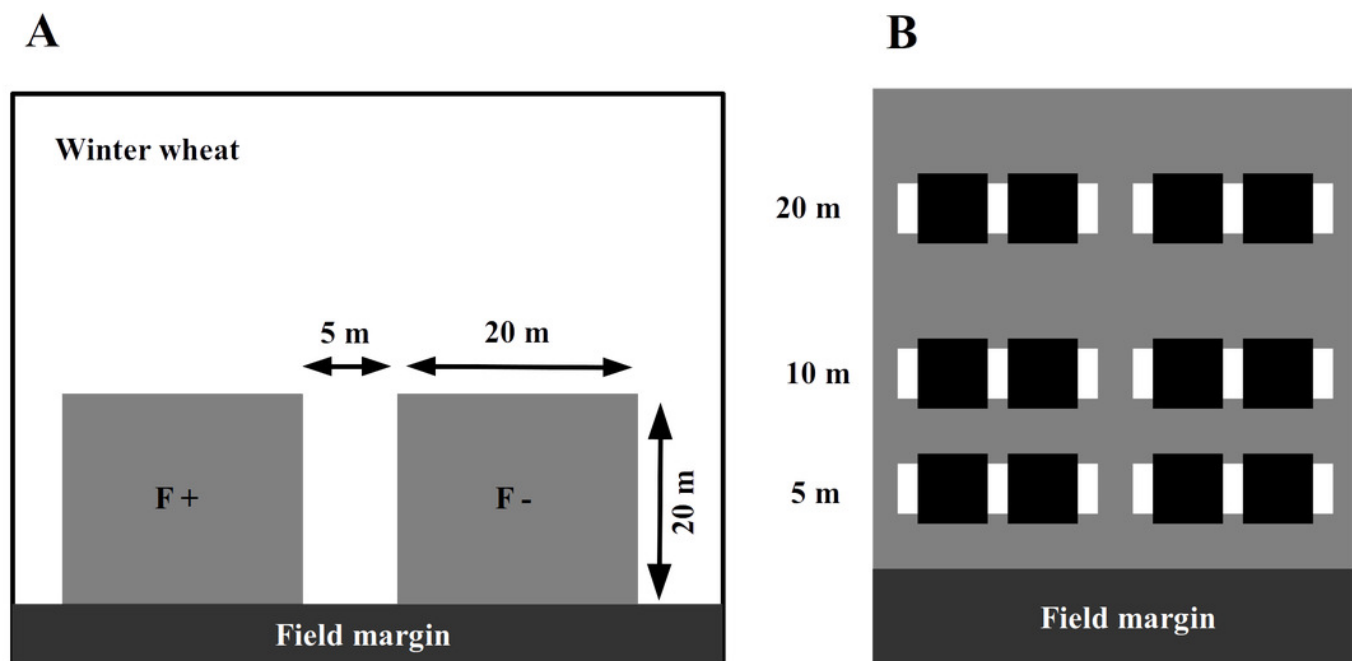
Figure 2

Response of aphid abundance (a), leaf spot prevalence (b) and winter wheat yield (c, d) to landscape configuration or complexity.

The yield was estimated by the ear (c) and grain (d) mass (g/m^2). The portrayed values are means with whiskers representing 95% confidence intervals. Different capital letters above indicate significant differences.
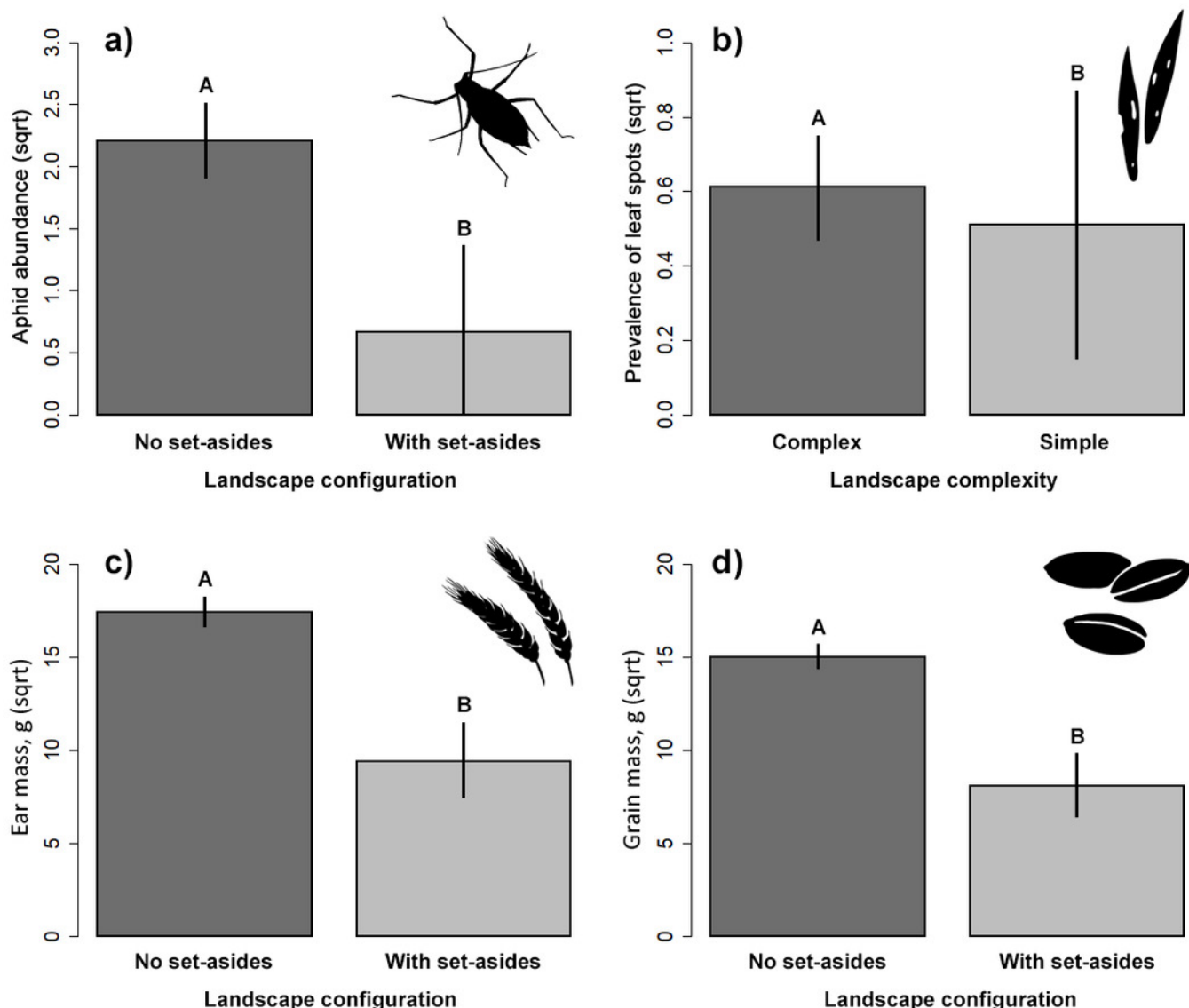
Figure 3

Response of the abundance for ground beetles (a, b), and spiders (c, d) to landscape configuration and complexity.

The portrayed values are means with whiskers representing 95% confidence intervals.

Different capital letters above indicate significant differences.