Supplementary material of the article

Animal biodiversity in cider apple orchards: simultaneous environmental drivers and effects on insectivory and pollination.

Rodrigo Martínez-Sastre[a], Marcos Miñarro[a] & Daniel García[b]*

[a] Servicio Regional de Investigación y Desarrollo Agroalimentario (SERIDA), Apdo. 13, E-33300, Villaviciosa, Asturias, Spain

[b] Depto. Biología de Organismos y Sistemas, Universidad de Oviedo, and Unidad Mixta de Investigación en Biodiversidad (CSIC-Uo-PA), C/Catedrático Rodrigo Uría s/n, E-33006, Oviedo, Asturias, Spain

* Corresponding author: danielgarcia@uniovi.es

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Appendix A. List of animal species recorded in cider apple orchards

Table A1. List of species of forest insectivorous birds recorded in cider apple orchards in this study.

Scientific name	Common name
Aegithalos caudatus	Long-tailed tit
Anthus trivialis	Tree pipit
Certhia brachydactyla	Short-toed treecreeper
Cettia cetti	Cetti's warbler
Cyanistes caeruleus	Eurasian blue tit
Dendrocopos major	Great spotted woodpecker
Erithacus rubecula	European robin
Ficedula hypoleuca	European pied flycatcher
Fringilla coelebs	Common chaffinch
Garrulus glandarius	Eurasian jay
Hippolais polyglotta	Melodious warbler
Lanius collurio	Red-backed shrike
Lophophanes cristatus	European crested tit
Oriolus oriolus	Eurasian golden oriole
Parus major	Great tit
Periparus ater	Coal tit
Phoenicurus phoenicurus	Common redstart
Phylloscopus collybita/ibericus	Common/Iberian chiffchaff
Picus viridis	Green woodpecker
Prunella modularis	Dunnock
Regulus ignicapilla	Common firecrest
Regulus regulus	Goldcrest
Sitta europaea	Eurasian nuthatch
Sylvia atricapilla	Eurasian blackcap
Sylvia borin	Garden warbler
Sylvia communis	Common whitethroat
Troglodytes troglodytes	Eurasian wren
Turdus iliacus	Redwing
Turdus merula	Common blackbird
Turdus philomelos	Song thrush
Turdus pilaris	Fieldfare
Turdus viscivorus	Mistle thrush

Table A2. List of species of pollinators identified in cider apple orchards in this study. Classified as either honey bee (HB), wild bee (WB), bumblebee (BB), hoverfly (HF), fly (F), beetle (B), or other (O).

Scientific name	Group	Scientific name	Group
Apis mellifera	HB	*Nomada succinta*	WB
Bombus pascuorum	BB	*Osmia bicornis*	WB
Bombus pratorum	BB	*Cheilosia pagana*	HF
Bombus terrestris	BB	*Chrysotoxum festivum*	HF
Andrena bicolor	WB	*Episyrphus balteatus*	HF
Andrena cyanomicans	WB	*Eristalis arbustorum*	HF
Andrena dorsata	WB	*Eristalis interrupta*	HF
Andrena flavipes	WB	*Eristalis pertinax*	HF
Andrena fulva	WB	*Eristalis similis*	HF
Andrena haemorrhoa	WB	*Eristalis tenax*	HF
Andrena humilis	WB	*Eupeodes corollae*	HF
Andrena lathyri	WB	*Helophilus pendulus*	HF
Andrena leptopyga	WB	*Melanostoma mellinum*	HF
Andrena minutula	WB	*Melanostoma scalare*	HF
Andrena nigroaenea	WB	*Meliscaeva auricollis*	HF
Andrena nitida	WB	*Neoascia podagrica*	HF
Andrena pilipes	WB	*Parhelophilus sp.*	HF
Andrena similis	WB	*Platycheirus albimanus*	HF
Andrena thoracica	WB	*Sphaerophoria scripta*	HF
Andrena trimmerana	WB	*Syrphus ribesii*	HF
Eucera sp.	WB	*Syrphus vitripennis*	HF
Halictidae sp1.	WB	*Volucella bombylans*	HF
Halictus (Seladonia) sp.	WB	*Xanthandrus comtus*	HF
Halictus crenicornis	WB	*Bombylius major*	F
Halictus scabiosae	WB	*Empis* sp.	F
Halictus tumulorum	WB	*Molobratia teutonus*	F
Lasioglossum calceatum	WB	*Neomyia cornicina*	F
Lasioglossum fulvicorne	WB	*Sarcophaga* sp.	F
Lasioglossum lativentre	WB	*Stevenia deceptoria*	F
Lasioglossum limbellum	WB	*Tricogena rubricosa*	F
Lasioglossum littorale	WB	*Zophomyia temula*	F
Lasioglossum lucidulum	WB	*Agrypnus murinus*	B
Lasioglossum malachurum	WB	*Hoplia hungarica*	B
Lasioglossum morio	WB	*Oedemera nobilis*	B
Lasioglossum pallens	WB	*Oxythyrea funesta*	B
Lasioglossum parvulum	WB	*Rhagonycha fulva*	B
Lasioglossum pauperatum	WB	*Trichius zonatus*	B
Lasioglossum pauxillum	WB	*Tropinota squalida*	B
Lasioglossum punctatissimum	WB	*Valgus hemipterus*	B
Lasioglossum puncticolle	WB	*Panorpa* sp.	O
Lasioglossum zonulum	WB	*Tenthredo koehleri*	O

Appendix B. Details of sentinel model experiment

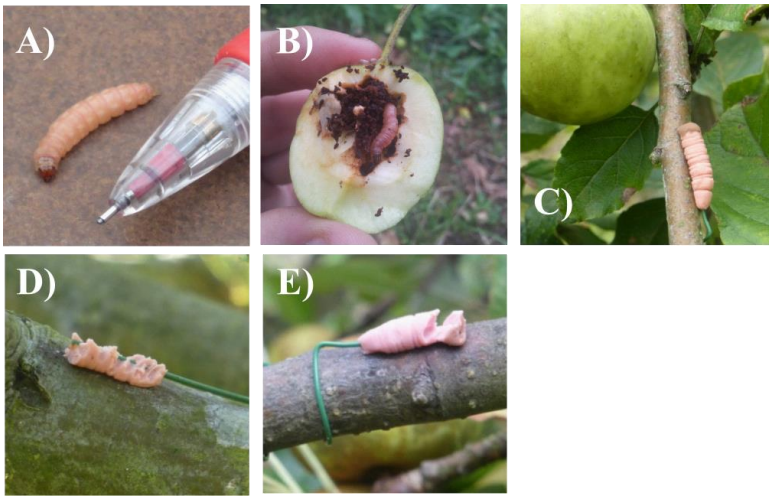

Figure B1. A-B) Views of codling moth larvae on cider apple; C) Plasticine sentinel model representing the codling moth caterpillar, attached to a cider apple branch; D-E) examples of sentinel models with signs of attack (pecking) by birds. Images by Daniel García (A, C-E) and Carlos Guardado (B).

Appendix C. Details of Principal Components Analysis (PCA) of landscape composition

Table C1. Results of Principal Components Analysis (PCA) accounting for the variability in the six general cover types in R1000 plots across orchards. PCAs were calculated based the percentages of cover of different cover types in R1000 plot around each orchard (quantified by GIS, ArcGIS9.3). PCA factor scores were obtained from the three first (Varimax) rotated eigenvectors of each analysis. The percentage of variance accounted for by each eigenvector, as well as the loadings of rotated factors (correlations, coefficients ≥ |0.700| highlighted in bold) are shown.

General ground cover types in R1000			
Factor	**PCA1**	**PCA2**	**PCA3**
% Variance	42.41	25.39	14.37
Exotic tree plantations	**0.973**	0.143	-0.083
Fruit tree plantations	0.156	0.104	**0.740**
Other habitats	-0.010	-0.187	**0.822**
Pastures	**-0.846**	-0.205	-0.331
Semi-natural woody habitats	0.050	**0.942**	-0.201
Urbanized ground	-0.429	**-0.805**	-0.184

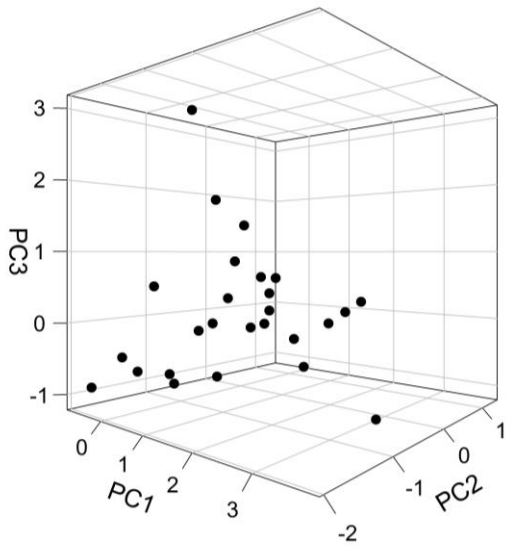

Figure C1. Representation of the multidimensional space determined by the vectors of PCA on cover types in R1000 plots across orchards. Dots represent different orchards.

Appendix D. Model selection process following a step-wise procedure.

Table D1. Models included in the procedure of step-wise deletion of non-significant (p>0.05) fixed factors from full models, for different response variables of bird and pollinator biodiversity. Values of Akaike Information Criterion (AIC) for the different full and nested models, and the results of likelihood ratio tests comparing nested models to their corresponding full model are shown. Non-significant predictors detected to be removed in the step-wise process are shown in bold.

Bird abundance	df	AIC	logLik	L.Ratio	p-value
PC1 + PC2 + PC3 + Orchard size + Apple canopy cover + Apple canopy thickness + Season + Year	11	727.684	-352.842		
PC2 + **PC3** + Orchard size + Apple canopy cover + Apple canopy thickness + Season + Year	10	728.676	-354.338	2.992	0.084
PC2 + Orchard size + Apple canopy cover + **Apple canopy thickness** + Season + Year	9	729.625	-355.812	5.941	0.051
PC2 + Orchard size + Apple canopy cover + Season + Year	8	726.963	-355.482	5.279	0.153
Orchard size + Apple canopy cover + Season + Year	7	727.867	-356.934	8.183	0.085
Apple canopy cover + Season + Year	6	727.281	-357.640	9.597	0.088
Bird richness	df	AIC	logLik	L.Ratio	p-value
PC1 + **PC2** + PC3 + Orchard size + Apple canopy cover + Apple canopy thickness + Season + Year	11	422.550	-200.275		
PC1 + **PC3** + Orchard size + Apple canopy cover + Apple canopy thickness + Season + Year	10	419.521	-199.760	1.029	0.310
PC1 + Orchard size + Apple canopy cover + Apple canopy thickness + Season + Year	9	416.650	-199.325	1.900	0.387
Orchard size + Apple canopy cover + **Apple canopy thickness** + Season + Year	8	415.044	-199.522	1.505	0.681
Orchard size + Apple canopy cover + Season + Year	7	410.804	-198.402	3.745	0.442

Table D1 (cont.)

Wild pollinator abundance	df	AIC	logLik	L.Ratio	p-value
PC1 + PC2 + PC3 + **Density ground cover** + Richness ground cover + Bloom + Apple canopy cover + Year	11	44.349	-11.175		
PC1 + PC2 + PC3 + **Richness ground cover** + Bloom + Apple canopy cover + Year	10	31.930	-5.965	10.419	0.001
PC1 + PC2 + PC3 + Bloom + **Apple canopy cover** + Year	9	22.229	-2.114	18.120	<0.001
PC1 + PC2 + PC3 + **Bloom** + Year	8	19.607	-1.804	18.742	<0.001
PC1 + PC2 + PC3 + Year	7	14.543	-0.272	21.806	<0.001
Wild pollinator richness	df	AIC	logLik	L.Ratio	p-value
PC1 + PC2 + PC3 + Density ground cover + Richness ground cover + Bloom + **Apple canopy cover** + Year	11	0.766	10.617		
PC1 + PC2 + PC3 + Density ground cover + Richness ground cover + Bloom + **Year**	10	-3.057	11.529	1.823	0.177
PC1 + PC2 + PC3 + **Density ground cover** + Richness ground cover + Bloom	9	-8.730	13.365	5.496	0.064
PC1 + PC2 + PC3 + **Richness ground cover** + Bloom	8	-22.274	19.137	17.040	<0.001
PC1 + **PC2** + PC3 + Bloom	7	-32.590	23.295	25.356	<0.001
PC1 + **PC3** + Bloom	6	-38.653	25.327	29.420	<0.001
PC1 + Bloom	5	-43.665	26.832	32.431	<0.001

Table D1 (cont.)

Wild bee abundance model	df	AIC	logLik	L.Ratio	p-value
PC1 + PC2 + PC3 + Density ground cover + Richness ground cover + Bloom + **Apple canopy cover** + Year	11	88.935	-33.467		
PC1 + PC2 + PC3 + Density ground cover + Richness ground cover + Bloom + **Year**	10	86.869	-33.435	0.065	0.789
PC1 + PC2 + PC3 + Density ground cover + Richness ground cover + Bloom	9	82.759	-32.380	2.175	0.337
PC2 + PC3 + **Density ground cover** + Richness ground cover + Bloom	8	76.809	-30.405	6.126	0.106
PC2 + PC3 + Richness ground cover + **Bloom**	7	65.674	-25.837	15.260	0.004
PC2 + PC3 + **Richness ground cover**	6	60.388	-24.194	18.547	0.002
PC2 + PC3	5	52.397	-21.199	24.537	<0.001
PC3	4	50.410	-21.159	25.014	<0.001
Wild bee richness model	df	AIC	logLik	L.Ratio	p-value
PC1 + PC2 + PC3 + Density ground cover + **Richness ground cover** + Bloom + Apple canopy cover + Year	11	42.828	-10.414		
PC1 + PC2 + PC3 + Density ground cover + Bloom + **Apple canopy cover** + Year	10	34.331	-7.166	6.497	0.011
PC1 + PC2 + PC3 + **Density ground cover** + Bloom + Year	9	32.235	-7.118	6.593	0.037
PC1 + PC2 + PC3 + Bloom + **Year**	8	19.942	-1.971	16.886	<0.001
PC1 + PC2 + **PC3** + Bloom	7	15.615	-0.808	19.213	<0.001
PC1 + PC2 + Bloom	6	11.237	0.381	21.591	<0.001
PC2 + Bloom	5	7.185	1.407	23.643	<0.001
Bloom	4	3.586	2.206	25.745	<0.001

Appendix E. Comparison between pollination treatments

Table E1. Results of Generalized Linear Mixed Models evaluating the effects of pollination treatments (hand vs. open pollination) on fruit set and seed set. Models included the variance (±SD) estimate for tree and orchard identity, considered as random factors. Response variables were fitted by considering a binomial error distribution (logit link).

Fruit set			
Predictors	**Estimate ± SE/SD**	**z**	**P**
Intercept	-0.109 ± 0.127	-0.857	0.391
Treatment (Open-pollination)	-0.886 ± 0.027	-33.353	<0.001
Tree [Orchard] (random factor)	0.276 ± 0.525		
Orchard (random factor)	0.321 ± 0.567		
Seed set			
Predictors	**Estimate ± SE/SD**	**z**	**P**
Intercept	1.554 ± 0.068	22.74	<0.001
Treatment (Open-pollination)	-0.795 ± 0.022	-36.85	<0.001
Tree [Orchard] (random factor)	0.141 ± 0.375		
Orchard (random factor)	0.066 ± 0.256		

Appendix F. Non-linear response of bird biodiversity to semi-natural woody vegetation.

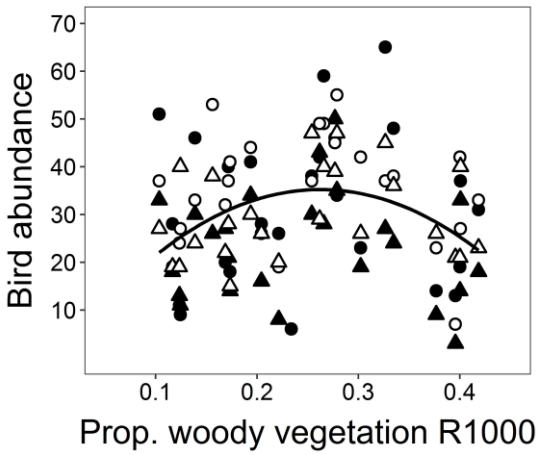

Figure F1. Results of polynomial (quadratic) regression model relating the proportion of semi-natural woody vegetation cover in a 1000-m radius around apple orchards with the abundance of forest insectivorous birds. Colors indicate different years, 2015-2016 (black) and 2016-2017 (white). Seasons are indicated with different shapes for Autumn-Winter (circles) and Spring-Summer (triangles).

Table F1. Generalized Linear Mixed Model evaluating the effect of the cover of semi-natural woody habitat (SNWH, 10000 m radius centered on the sampling station of each orchard) and its quadratic term on the abundance of forest insectivorous birds (Gaussian distribution, identity link). The variance (±SD) estimate for orchard identity, considered as a random factor, is also shown.

Bird abundance			
Predictors	**Estimate ± SE/SD**	**t**	**P**
Intercept	1.62 ± 14.06	0.12	0.909
SNWH	250.01 ± 118.92	2.10	0.048
$SNWH^2$	-476.17 ± 225.18	-2.11	0.047
Orchard (random factor)	68.54 ± 60.60		

Appendix G. Trade-offs between biodiversity groups and between ecological functions.

Table G1. Pearson correlation coefficients (r), and their respective significance levels (values P < 0.05 in bold), between abundance/richness of insectivorous birds and pollinator insects (spring 2016), as well as between ecological functions, measured as insectivory and fruit set (spring 2016)

	r	**N**	**P**
Wild bee abundance & Bird abundance	0.380	21	0.090
Wild bee abundance & Bird richness	**0.520**	21	**0.016**
Wild bee richness & Bird abundance	-0.060	21	0.800
Wild bee richness & Bird richness	0.130	21	0.580
Wild pollinator abundance & Bird abundance	-0.190	21	0.410
Wild pollinator abundance & Bird rich	-0.131	21	0.571
Wild pollinator richness & Bird abundance	-0.22	21	0.340
Wild pollinator richness & Bird richness	-0.083	21	0.720
Fruit set & Proportion of attacked caterpillar models	0.364	21	0.105