Birds as suppliers of pest control in cider apple orchards: avian biodiversity drivers and insectivory effect.

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Supplementary material

Figure A1. Examples of the environmental context of cider apple orchards in Asturias (N Spain). At the large scale (A), orchards (an example is delimited by yellow lines) are embedded in a highly variegated landscape, containing a fine-grained mosaic of orchards, livestock pastures, annual crops (e.g. corn), timber (eucalyptus) plantations, human infrastructures, and semi-natural woody vegetation patches, mostly temperate broad-leaved forest (dominated by oak *Quercus robur*, and chestnut *Castanea sativa*), riverine forest (with common alder *Alnus glutinosa*), hedgerows, and heathland patches (with heather *Calluna vulgaris* and *Erica* spp., and common gorse *Ulex europaeus*). At the small scale of immediate neighborhoods (B-E), apple orchards are typically surrounded, total or partially, by natural woody vegetation in the form of hedgerows or small forest patches. Tall hedgerows (B) may harbor trees (*Quercus robur*, *Salix caprea*, *Fraxinus excelsior*, *Populus nigra*, *Laurus nobilis, Alnus glutinosa*), whereas medium-to-low height hedgerows (C) are mostly composed of treelets and shrubs (*Crataegus monogyna*, *Prunus spinosa*, *Corylus avellana*, *Lygustrum vulgaris*, *Rhamnus alaternus*, *Euonymus europaeus*), scrub (*Rubus fruticosus/ulmifolius*, *Rosa* sp.) and vines (*Smilax aspera*, *Hedera helix*). Apple orchards are also frequently adjacent to small patches of semi-natural forests (D) composed of the same coterie of woody species as hedgerows. Isolated, remnant trees (*Quercus robur*, *Populus nigra*) are also found within some orchards (E). White arrows indicate apple tree rows within the orchards. Pictures by Daniel García (B, E) and Marcos Miñarro (C, D)

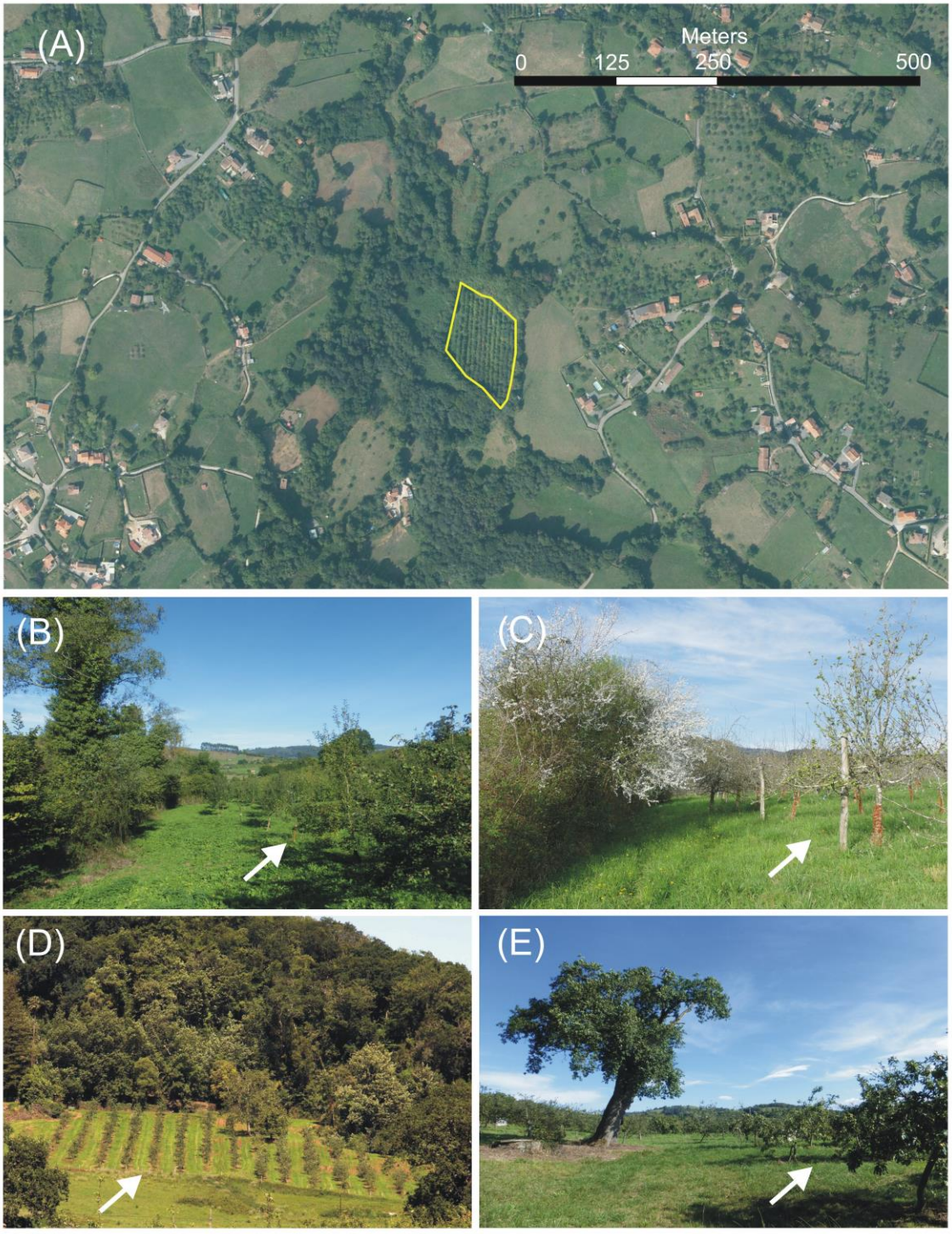
(A)
Meters
0
125
250
500
(B)
(C)
(D)
(E)

Table A1. Spatial information on cider apple orchards selected for sampling. Season of sampling (AW: Autumn-Winter 2016, SS: Spring-Summer 2016) is also indicated.

Site name	Municipality	UTM coordinates (30 T)		Surface (Ha)	Sampling
		North	East		
La Camocha	Gijón	284227.9	4818818.4	1.62	SS
La Quemada	Gijón	285482.5	4819626.5	2.90	AW, SS
Lavandera	Gijón	285573.2	4816297.0	1.58	AW, SS
Caldones	Gijón	287212.6	4818898.7	2.38	AW, SS
Quintana	Gijón	287314.7	4814681.4	0.54	AW, SS
Santurio	Gijón	287688.2	4820503.9	0.64	AW, SS
Valdornón	Gijón	288564.2	4813974.3	4.13	AW
Noreña	Noreña	280089.7	4809113.0	1.84	AW, SS
Masaveu	Sariego	295411.3	4808665.9	20.59	AW, SS
Verdera	Sariego	297484.2	4808767.3	0.81	AW, SS
Tiñana	Siero	276052.0	4805046.9	0.82	AW, SS
Muñiz	Siero	277001.2	4805902.6	1.39	AW, SS
El Obispu	Siero	278198.1	4805499.4	1.80	AW, SS
Pañeda	Siero	280271.3	4811705.8	1.27	AW, SS
La Salve	Siero	285563.8	4806559.4	4.86	AW, SS
Collao	Siero	290833.4	4807344.8	1.57	AW, SS
Camoca	Villaviciosa	299114.7	4814066.1	0.81	AW, SS
Bustariega	Villaviciosa	300418.3	4814382.2	5.36	AW, SS
Poreñu	Villaviciosa	301888.5	4812201.2	6.77	AW, SS
Sorribes	Villaviciosa	302217.5	4817112.4	1.43	AW, SS
El Gaiteru	Villaviciosa	304304.1	4818459.1	6.14	AW, SS
Cayao	Villaviciosa	304979.3	4814202.5	1.71	AW, SS
Tornón	Villaviciosa	305418.0	4819490.4	5.60	AW, SS
Ceyanes	Villaviciosa	307251.9	4814285.2	1.01	AW, SS
La Ría	Villaviciosa	307726.5	4821047.3	3.36	AW, SS
Seloriu	Villaviciosa	310225.9	4820866.2	2.42	AW, SS

Figure A2. Details of the bird exclusion experiment, showing (A) one branch (excluded treatment) where access by birds is precluded by a cylindrical cage of wire mesh and installed before bud burst; (B) a detail of a rosy aphid colony; (C) the procedure for the experimental infestation of apple shoots with rosy aphid females; and (D) a shoot infested with rosy apple aphids showing signs of damage (curled leaves). Pictures by Daniel García (A, C) and Marcos Miñarro (B, D).

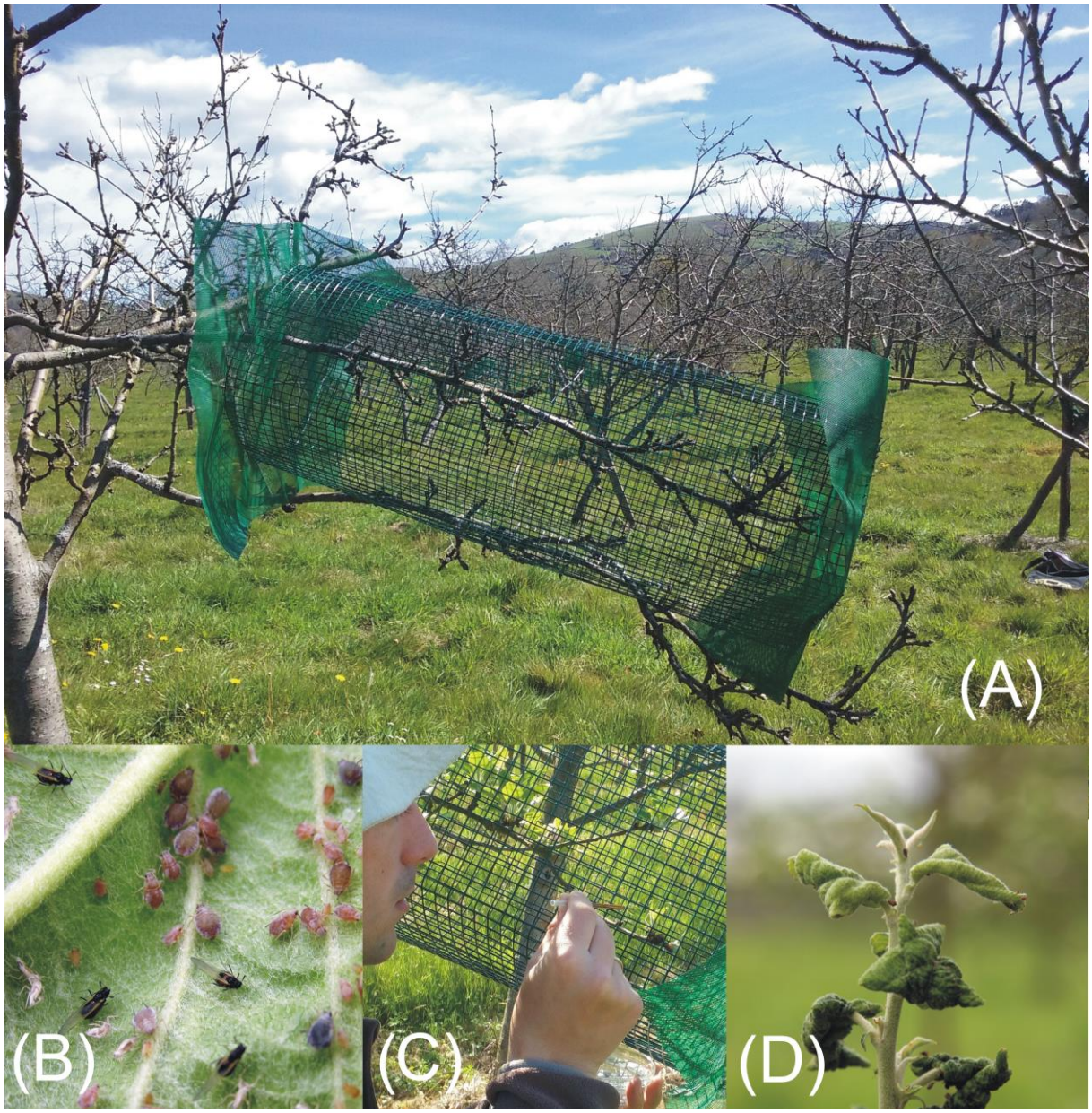

Table A2. List of birds observed in the study, indicating the total number of observations (number of individual birds recorded) in Autumn-Winter 2015 and Spring-Summer 2016 seasons. The classification of the different species as "forest insectivore" or not (-/+) is also shown.

Species name	Common name	Autumn-Winter	Spring-Summer	Forest Insectivore
Acrocephalus schoenobaenus	Sedge warbler	1	0	-
Aegithalos caudatus	Long-tailed tit	107	52	+
Anthus pratensis	Meadow pipit	21	6	-
Anthus trivialis	Tree pipit	0	17	+
Carduelis carduelis	European goldfinch	163	83	-
Carduelis spinus	Eurasian siskin	27	1	-
Certhia brachydactyla	Short-toed treecreeper	10	22	+
Cettia cetti	Cetti's warbler	3	1	+
Chloris chloris	European greenfinch	9	46	-
Cisticola juncidis	Zitting cisticola	0	1	-
Columba palumbus	Common wood pigeon	16	35	-
Corvus corone	Carrion crow	22	7	-
Corvus corax	Common raven	12	1	-
Cyanistes caeruleus	Eurasian blue tit	155	104	+
Dendrocopos major	Great spotted woodpecker	19	28	+
Emberiza cia	Rock bunting	1	1	-
Emberiza citrinella	Yellowhammer	0	1	-
Erithacus rubecula	European robin	604	330	+
Ficedula hypoleuca	European pied flycatcher	37	0	+
Fringilla coelebs	Common chafinch	154	20	+
Garrulus glandarius	Eurasian jay	58	56	+
Lanius collurio	Red-backed shrike	0	3	+
Motacilla alba	White wagtail	2	11	-
Motacilla cinerea	Grey wagtail	1	0	-
Oriolus oriolus	Eurasian golden oriole	0	17	+
Periparus ater	Coal tit	19	26	+
Parus major	Great tit	157	142	+
Passer domesticus	House sparrow	0	52	-
Phoenicurus ochruros	Black redstart	1	0	-
Phoenicurus phoenicurus	Common redstart	0	9	+
Phylloscopus collybita/ibericus	Common/Iberian chiffchaff	51	90	+
Pica pica	Eurasian magpie	57	47	-
Picus viridis	Green woodpecker	44	35	+
Prunella modularis	Dunnock	2	0	+
Pyrrhula pyrrhula	Eurasian bullfinch	19	59	-
Regulus ignicapilla	Common firecrest	84	24	+
Regulus regulus	Goldcrest	3	0	+
Saxicola rubetra	Whinchat	0	2	-
Saxicola torquatus	African stonechat	3	2	-
Serinus serinus	European serin	33	83	-
Sitta europaea	Eurasian nuthatch	6	0	+

Table A2 (cont.)

Species name	Common name	Autumn-Winter	Spring-Summer	Forest Insectivore
Sturnus unicolor	Spotless starling	18	10	-
Sturnus vulgaris	Common starling	79	15	-
Sylvia atricapilla	Eurasian blackcap	191	210	+
Sylvia communis	Common whitethroat	0	1	+
Sylvia undata	Dartford warbler	4	1	-
Troglodytes troglodytes	Eurasian wren	107	204	+
Turdus iliacus	Redwing	64	0	+
Turdus merula	Common blackbird	233	341	+
Turdus philomelos	Song thrush	36	98	+
Turdus pilaris	Fieldfare	3	0	+
Turdus viscivorus	Mistle thrush	3	1	+

Table A3. Results of Generalized Linear Mixed Models evaluating the effects of landscape structure, orchard features and sampling season (Autumn-Winter vs Spring-Summer) on the composition of the assemblages of forest insectivorous birds (as depicted by dimensions of NMDS analysis) in the R50 plot. The variance estimate for orchard identity, considered as a random factor, is also shown.

NMDS1				
Predictors	Estimate ± SE	Denominator df	t	P
Prop. woody vegetation R1000	0.002 ± 0.02	19.43	0.16	0.876
Prop. woody vegetation R50	-0.01 ± 0.02	19.95	-0.42	0.678
Apple canopy cover	0.02 ± 0.02	20.75	1.12	0.274
Apple canopy thickness	-0.02 ± 0.02	19.84	-0.99	0.333
Orchard size	-0.012 ± 0.02	19.23	-0.69	0.498
Season	-0.15 ± 0.02	25.16	-8.00	<0.0001
Random factor	Variance Estimate ± SD			
Orchard	0.02 ± 0.05			
NMDS2				
Predictors	Estimate ± SE	Denominator df	t	P
Prop. woody vegetation R1000	0.03 ± 0.03	18.10	1.31	0.207
Prop. woody vegetation R50	0.03 ± 0.03	28.56	0.97	0.345
Apple canopy cover	0.04 ± 0.03	19.28	1.53	0.143
Apple canopy thickness	0.01 ± 0.03	18.47	0.39	0.700
Orchard size	0.02 ± 0.03	17.93	0.75	0.463
Season	0.02 ± 0.02	22.72	1.22	0.234
Random factor	Variance Estimate ± SD			
Orchard	0.39 ± 0.02			

Figure A3. Results of piecewise regression models relating the proportion of woody vegetation cover in a 1000-m radius (R1000) around apple orchards with the abundance and the richness of forest insectivorous birds in the 50-m radius (R50) sampling plot. Bird abundance and richness values account for the cumulative number of individuals and species across seasons (Autumn-Winter and Spring-Summer). Only apple orchards sampled across both seasons were included (N = 24). Slopes (±SE), their t-values and their significance levels (*: $P \leq 0.05$; n.s.: $P > 0.05$) are shown for broken-line relationships (initial guess for breakpoint was provided at psi = 0.28). Analyses were carried out using the R package *segmented* (version 1.4; Muggeo, VMR, 2008. segmented: an R Package to Fit Regression Models with Broken-Line Relationships. R News, 8/1, 20-25).