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SUPPORTING INFORMATION

Enhancing ecosystem services in apple orchards: nest boxes increase pest control by insectivorous birds

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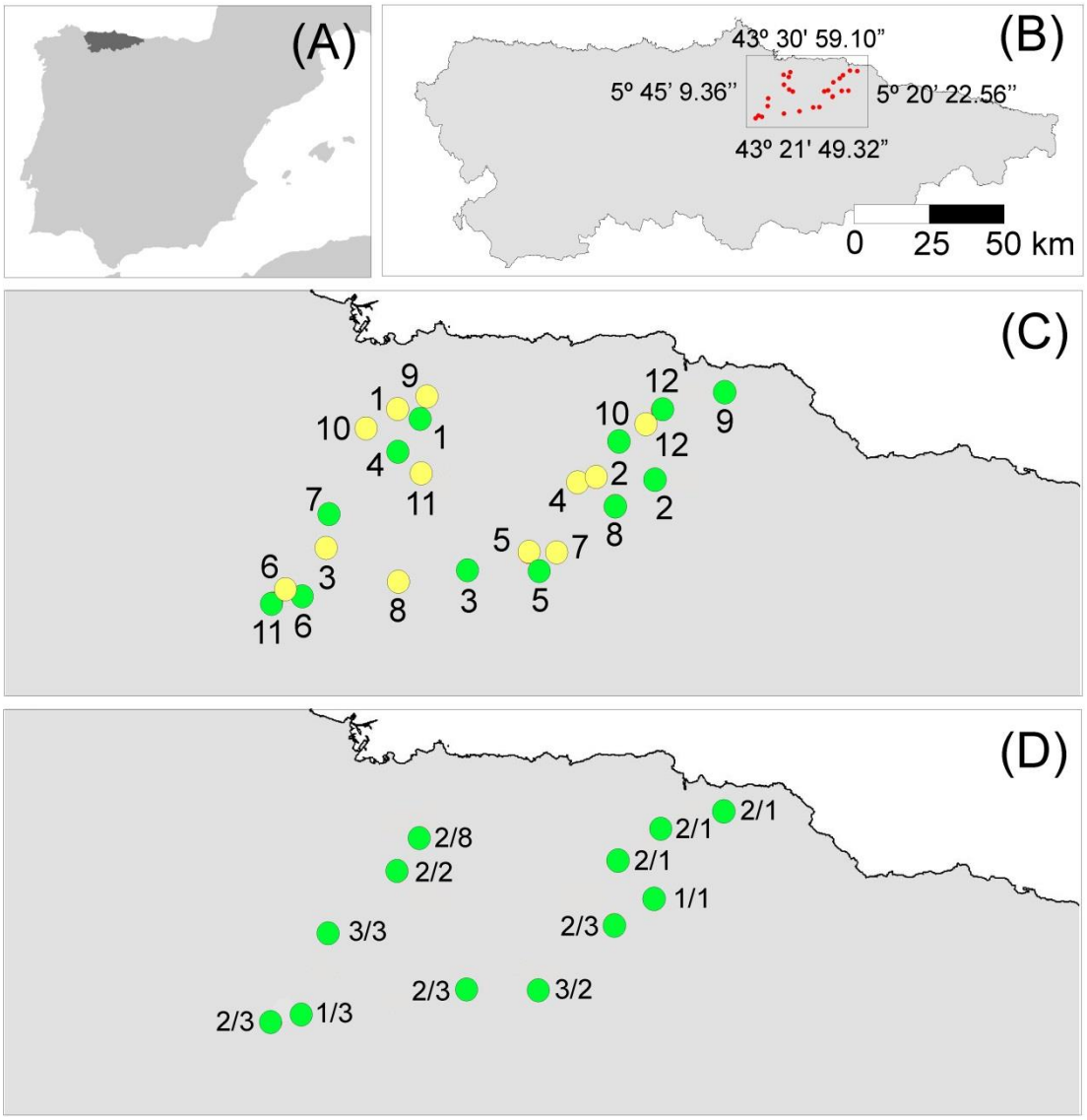

Figure S1. Schematic representation of study sites and spatial design, showing: A) the region of study (Asturias province in dark gray within the Iberian Peninsula); B) the location of the twenty-four orchards under study; C) a detail of the location of the twelve pairs (identified by different numbers) of orchards corresponding to nest box (in green) and control (in yellow) groups; D) a detail of the number (2018/2019) of occupied nest boxes (i.e. sampling stations) in the different nest box orchards (equivalent numbers of sampling stations were considered in the paired control orchards).

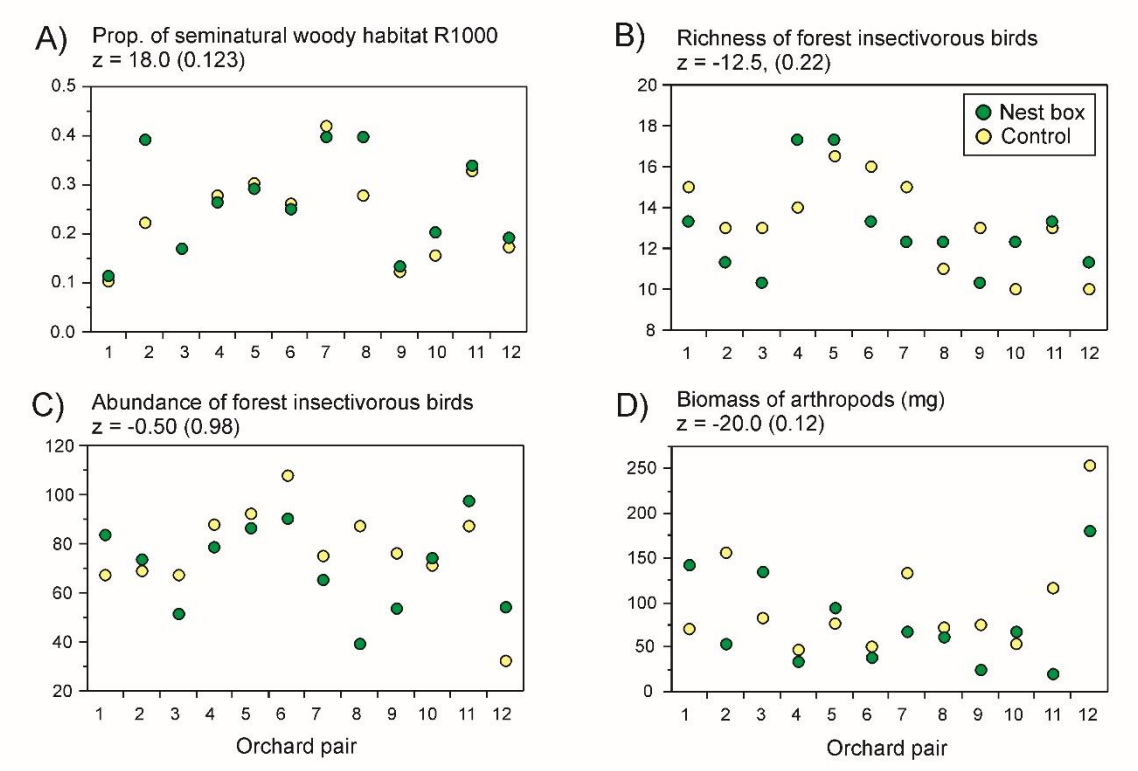

Figure S2. Comparison between orchard groups (nest boxes vs control) considering different orchard pairs (numbered 1 to 12) for values of: A) the proportion of seminatural woody habitat within a radius of 1000 m from orchard center, estimated from a digitized layer based on 1:5000-scale (2014) orthophotographs (García et al., 2018); B) the richness of forest insectivorous birds within a 50-m plot in the orchard, estimated as the cumulative number of species observed in 8 fortnightly censuses from April to July 2016 (García et al., 2018); C) the abundance of forest insectivorous birds, estimated as the cumulative number of individuals in the same censuses; and d) the abundance of arthropods on apple trees, estimated as the cumulative biomass (mg) of arthropods obtained from beating samples of five trees per orchard in June 2016 (Martínez-Sastre et al., 2020). For each variable, the results of a paired Wilcoxon test comparing control and nest box orchards are also shown (P-value between brackets).

References

García, D., Miñarro, M., & Martínez-Sastre, R. (2018). Birds as suppliers of pest control in cider apple orchards: Avian biodiversity drivers and insectivory effect. *Agriculture, Ecosystems and Environment*, *254*, 233-243.

Martínez-Sastre, R., Miñarro, M., & García, D. (2020). Animal biodiversity in cider-apple orchards: simultaneous environmental drivers and effects on insectivory and pollination. *Agriculture, Ecosystems and Environment*, *295*, 106918.

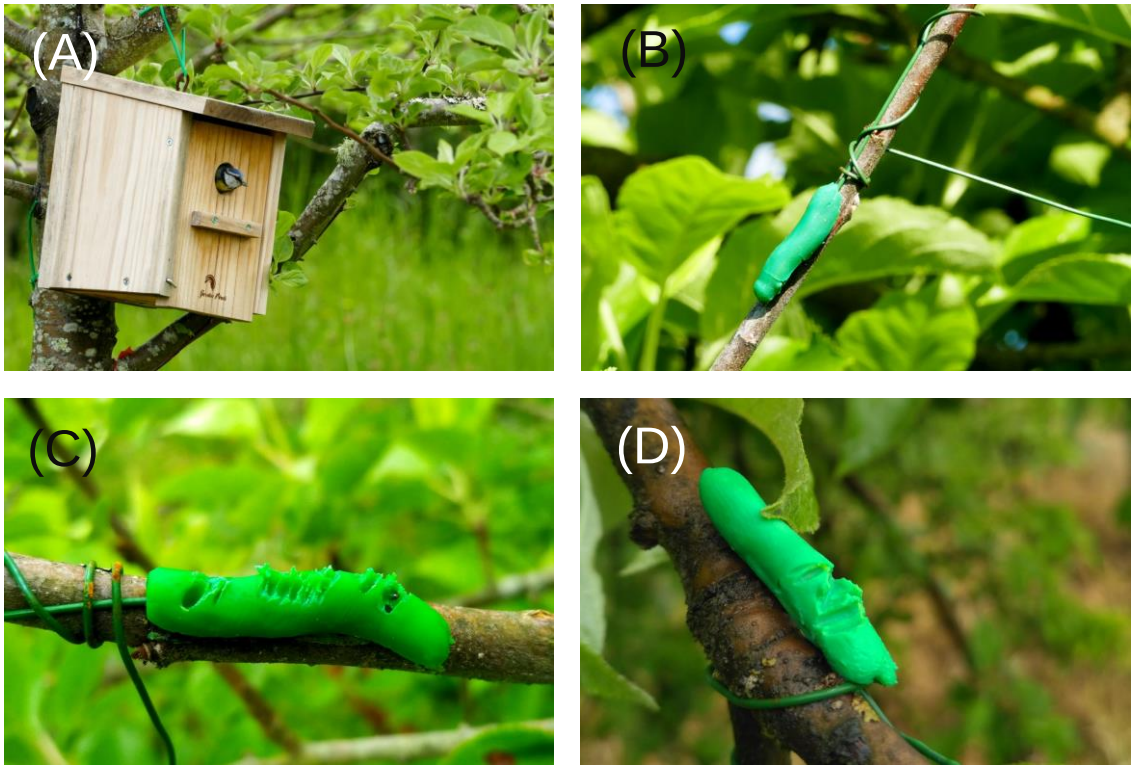

Figure S3. Examples of the nest boxes used for the experiment, in this case occupied by blue tit (A), plasticine model imitating the natural position of a real caterpillar (B) and plasticine models with beak marks after bird attack (C) and (D). Photos by Marcos Miñarro.

Figure S4. Examples of photographs taken during the study to identify preys carried by adult birds to feed nestlings. From left to right and from top to bottom: blue tit with blossom weevil larvae, woolly aphid, green aphid, rosy aphid, green weevils, homopterans and earwig; great tit with five different caterpillars (one per photograph), grasshopper, crane-fly, beetle, two spiders (one per photograph) and earwig; and common redstart with flying ants, three caterpillars (one per photograph), two spiders (one per photograph) and woodlouse. Photos by Marcos Miñarro and Antonio López.

Table S1. Summary of Generalized linear mixed models, based on different families of error distribution and link functions, evaluating the effect of experimental treatment (control vs nest box) and distance on the occurrence (binomial) and the number of individuals of apple pests (other families). Variance for random factors, sampling station and orchard (nested within orchards pair) is also shown. Values of Akaike Information Criterion (AIC), AIC difference and AIC weight used for model selection are shown

Apple pests	Predictors	Estimate ± SE/SD	t / z	P	AIC	ΔAIC	AIC weight
Binomial, logit	Treatment (nest box)	-0.82 ± 0.35	-2.37	0.018	262.8	0	0.999
	Distance	0.01 ± 0.01	1.09	0.275			
	Sampling station	0.00 ± 0.00					
	Orchard [Pair]	0.08 ± 0.28					
Poisson, log	Treatment (nest box)	-0.45 ± 0.28	-1.67	0.094	672.3	409.5	0.000
	Distance	0.01 ± 0.01	0.79	0.426			
	Sampling station	0.68 ± 0.82					
	Orchard [Pair]	0.00 ± 0.00					
Zero-Inflated Poisson, log	Treatment (nest box)	-0.41 ± 0.29	-1.39	0.162	644.6	381.8	0.000
	Distance	-0.01 ± 0.01	-0.07	0.940			
	Sampling station	0.79 ± 0.88					
	Orchard [Pair]	0.00 ± 0.00					
Negative Binomial, log	Treatment (nest box)	-0.15 ± 0.26	-1.99	0.047	597.2	334.4	0.000
	Distance	0.01 ± 0.01	1.24	0.179			
	Sampling station	0.00 ± 0.00					
	Orchard [Pair]	0.14 ± 0.37					
Zero-Inflated Negative Binomial, log	Treatment (nest box)	-0.51 ± 0.26	-1.99	0.047	599.2	336.4	0.000
	Distance	0.01 ± 0.01	1.34	0.179			
	Sampling station	0.00 ± 0.00					
	Orchard [Pair]	0.14 ± 0.37					

Table S2. Summary of Generalized linear mixed models based on different families of error distribution and link functions evaluating the effect of experimental treatment (control vs nest box) and distance on the number of individuals of natural enemies. Binomial family was not considered, due to the low frequency of zero values in the data (27 of 198 cases, Fig. 3 in the main text). Variance for random factors, sampling station and orchard (nested within orchards pair) is also shown. Values of Akaike Information Criterion (AIC), AIC difference and AIC weight used for model selection are shown.

Natural enemies	Predictors	Estimate ± SE/SD	t / z	P	AIC	ΔAIC	AIC weight
Poisson, log	Treatment (nest box)	0.13 ± 0.17	0.78	0.438	769.9	1.4	0.214
	Distance	0.01 ± 0.01	0.33	0.740			
	Sampling station	0.04 ± 0.21					
	Orchard [Pair]	0.09 ± 0.31					
Zero-Inflated Poisson, log	Treatment (nest box)	0.12 ± 0.16	0.74	0.458	770.1	1.6	0.194
	Distance	0.00 ± 0.01	0.29	0.773			
	Sampling station	0.04 ± 0.18					
	Orchard [Pair]	0.09 ± 0.31					
Negative Binomial, log	Treatment (nest box)	0.14 ± 0.17	0.84	0.400	768.5	0	0.432
	Distance	0.01 ± 0.01	0.43	0.667			
	Sampling station	0.01 ± 0.11					
	Orchard [Pair]	0.11 ± 0.33					
Zero-Inflated Negative Binomial, log	Treatment (nest box)	0.14 ± 0.17	0.84	0.400	770.5	5	0.159
	Distance	0.01 ± 0.01	0.43	0.667			
	Sampling station	0.01 ± 0.11					
	Orchard [Pair]	0.11 ± 0.33					

Table S3. Summary of Generalized linear mixed models based on different families of error distribution and link functions evaluating the effect of experimental treatment (control vs nest box) and distance on the number of individuals of all arthropods. Binomial and zero-inflated families were not considered, due to the absence of zero values in the data (Fig. 3 in the main text). Variance for random factors, sampling station and orchard (nested within orchards pair) is also shown. Values of Akaike Information Criterion (AIC), AIC difference and AIC weight used for model selection are shown.

All arthropods	Predictors	Estimate ± SE/SD	t / z	P	AIC	ΔAIC	AIC weight
Gamma, log	Treatment (nest box)	-0.12 ± 0.15	-0.82	0.414	1108.0	0	0.990
	Distance	-0.00 ± 0.01	-0.68	0.494			
	Sampling station	0.06 ± 0.25					
	Orchard [Pair]	0.02 ± 0.13					
Poisson, log	Treatment (nest box)	-0.12 ± 0.13	-0.91	0.362	1117.3	9.3	0.009
	Distance	0.00 ± 0.01	-0.58	0.561			
	Sampling station	0.09 ± 0.31					
	Orchard [Pair]	0.05 ± 0.21					
Negative Binomial, log	Treatment (nest box)	-0.11 ± 0.13	-0.82	0.413	1140.9	32.9	0.001
	Distance	0.00 ± 0.00	-0.18	0.860			
	Sampling station	0.05 ± 0.22					
	Orchard [Pair]	0.05 ± 0.22					

Table S4. Summary of Generalized linear mixed models, based on different families of error distribution and link functions, evaluating the effect of bird species (blue tit vs great tit) and distance on the occurrence (binomial) and the number of individuals of apple pests (other families). Variance for random factors, sampling station and orchard is also shown. Values of Akaike Information Criterion (AIC), AIC difference and AIC weight used for model selection are shown

Apple pests	Predictors	Estimate ± SE/SD	t / z	P	AIC	ΔAIC	AIC weight
Binomial, logit	Species (great tit)	-0.46 ± 0.52	-0.93	0.355	135.2	0	0.999
	Distance	0.00 ± 0.01	0.40	0.687			
	Sampling station	0.00 ± 0.00					
	Orchard	0.53 ± 0.73					
Poisson, log	Species (great tit)	0.16 ± 0.53	0.31	0.758	311.9	176.7	0.000
	Distance	-0.01 ± 0.01	-0.31	0.760			
	Sampling station	1.31 ± 1.15					
	Orchard	0.09 ± 0.29					
Zero-Inflated Poisson, log	Species (great tit)	0.29 ± 0.54	0.543	0.587	284.2	149.0	0.000
	Distance	-0.01 ± 0.01	-0.21	0.611			
	Sampling station	1.29 ± 1.13					
	Orchard	0.00 ± 0.00					
Negative Binomial, log	Species (great tit)	0.21 ± 0.53	0.40	0.690	274.0	138.8	0.000
	Distance	0.01 ± 0.01	0.14	0.889			
	Sampling station	0.73 ± 0.85					
	Orchard	0.10 ± 0.32					
Zero-Inflated Negative Binomial, log	Species (great tit)	0.21 ± 0.53	0.40	0.690	276.0	140.8	0.000
	Distance	0.01 ± 0.01	0.14	0.889			
	Sampling station	0.73 ± 0.85					
	Orchard	0.10 ± 0.32					

Table S5. Summary of Generalized linear mixed models based on different families of error distribution and link functions evaluating the effect of bird species (blue tit vs great tit) and distance on the number of individuals of natural enemies. Binomial family was not considered, due to the low frequency of zero values in the data (13 of 96 cases, Fig. S6). Variance for random factors, sampling station and orchard is also shown. Values of Akaike Information Criterion (AIC), AIC difference and AIC weight used for model selection are shown.

Natural enemies	Predictors	Estimate ± SE/SD	t / z	P	AIC	ΔAIC	AIC weight
Poisson, log	Species (great tit)	0.06 ± 0.20	0.30	0.765	382.4	0	0.374
	Distance	0.00 ± 0.00	0.63	0.530			
	Sampling station	0.07 ± 0.26					
	Orchard	0.24 ± 0.49					
Zero-Inflated Poisson, log	Species (great tit)	0.06 ± 0.20	0.30	0.765	383.4	1.0	0.227
	Distance	0.00 ± 0.00	0.63	0.530			
	Sampling station	0.07 ± 0.26					
	Orchard	0.24 ± 0.49					
Negative Binomial, log	Species (great tit)	0.14 ± 0.17	0.84	0.400	382.9	0.5	0.291
	Distance	0.01 ± 0.01	0.43	0.667			
	Sampling station	0.03 ± 0.18					
	Orchard	0.26 ± 0.33					
Zero-Inflated Negative Binomial, log	Species (great tit)	0.05 ± 0.19	0.27	0.782	384.9	2.5	0.107
	Distance	0.01 ± 0.01	0.64	0.520			
	Sampling station	0.03 ± 0.18					
	Orchard	0.25 ± 0.51					

Table S6. Summary of Generalized linear mixed models based on different families of error distribution and link function evaluating the effect of bird species (blue tit vs great tit) and distance on the number of individuals of all arthropods. Binomial and zero-inflated families were not considered, due to the very low frequency of zero values in the data (1 of 96 cases, Fig. S6). Variance for random factors, sampling station and orchard, is also shown. Values of Akaike Information Criterion (AIC), AIC difference and AIC weight used for model selection are shown.

All arthropods	Predictors	Estimate ± SE/SD	t / z	P	AIC	ΔAIC	AIC weight
Gamma, log	Species (great tit)	0.07 ± 0.18	0.37	0.708	535.1	0	0.999
	Distance	-0.00 ± 0.00	-0.24	0.806			
	Sampling station	0.07 ± 0.26					
	Orchard	0.03 ± 0.17					
Poisson, log	Species (great tit)	0.08 ± 0.16	0.46	0.646	562.7	27.6	0.000
	Distance	-0.00 ± 0.00	-0.86	0.389			
	Sampling station	0.11 ± 0.33					
	Orchard	0.07 ± 0.27					
Negative Binomial, log	Species (great tit)	0.06 ± 0.16	0.40	0.688	548.9	13.8	0.001
	Distance	-0.00 ± 0.00	-0.35	0.725			
	Sampling station	0.06 ± 0.26					
	Orchard	0.08 ± 0.28					

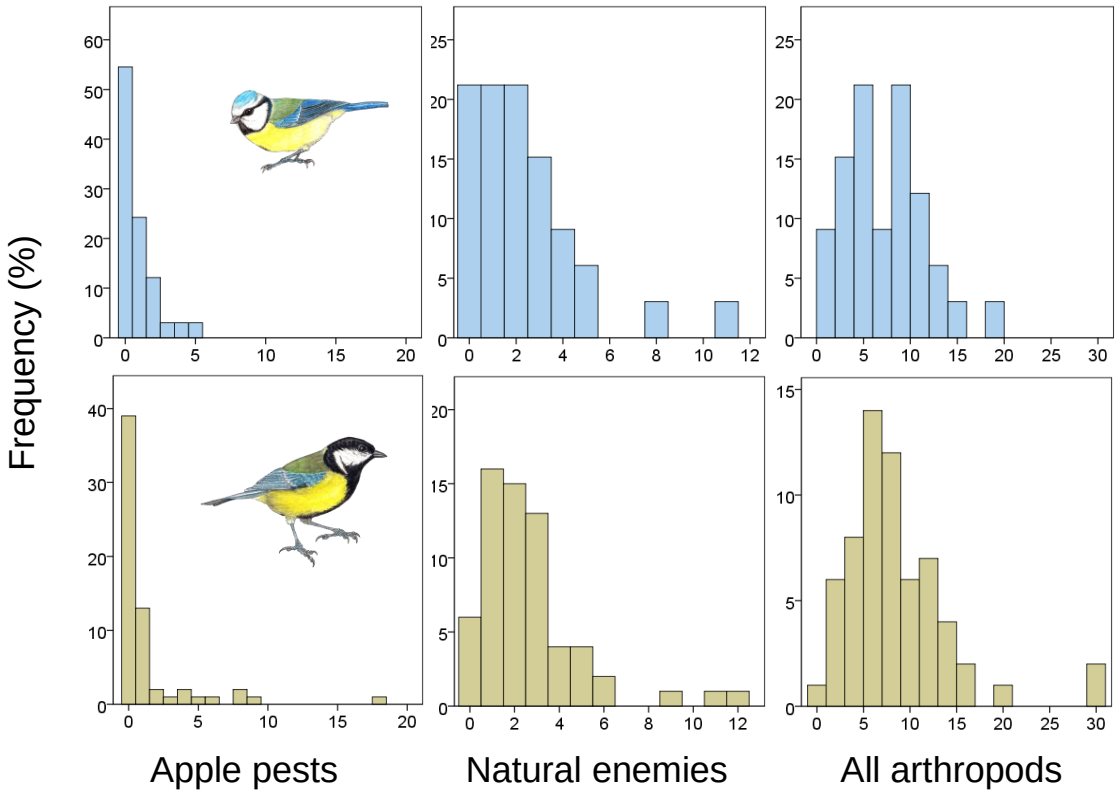

Figure S5. Distribution of the number of individuals of arthropods per tree collected after beating sampling in orchards around blue tit (blue) and great tit (brown) nest boxes. The percentage of frequency is shown separately for apple pests, natural enemies and all the sampled arthropods. Artwork by Daniel García.

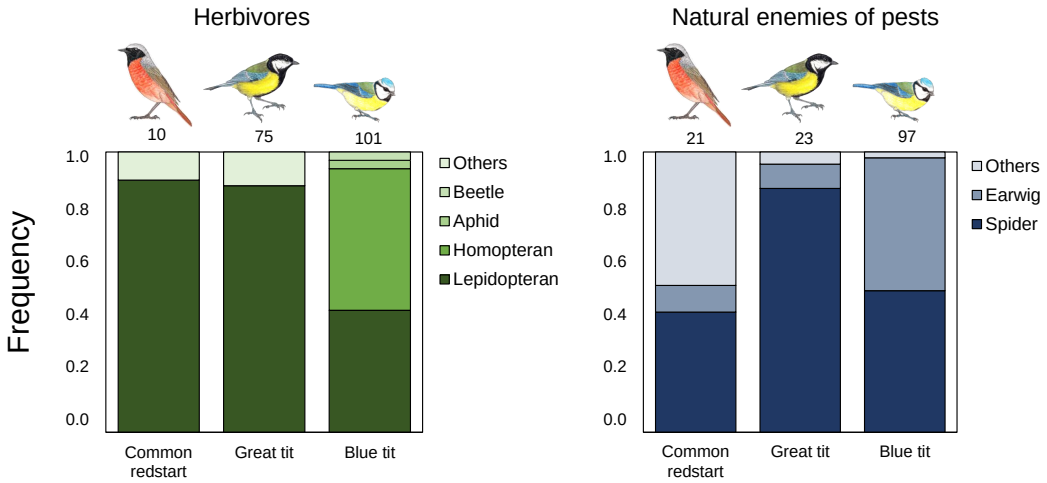

Figure S6. Frequency of preys carried by adults of the three observed bird species for the feeding of nestlings, distinguishing herbivores other than apple pests (left) and natural enemies of apple pests (right). Artwork by Daniel García.

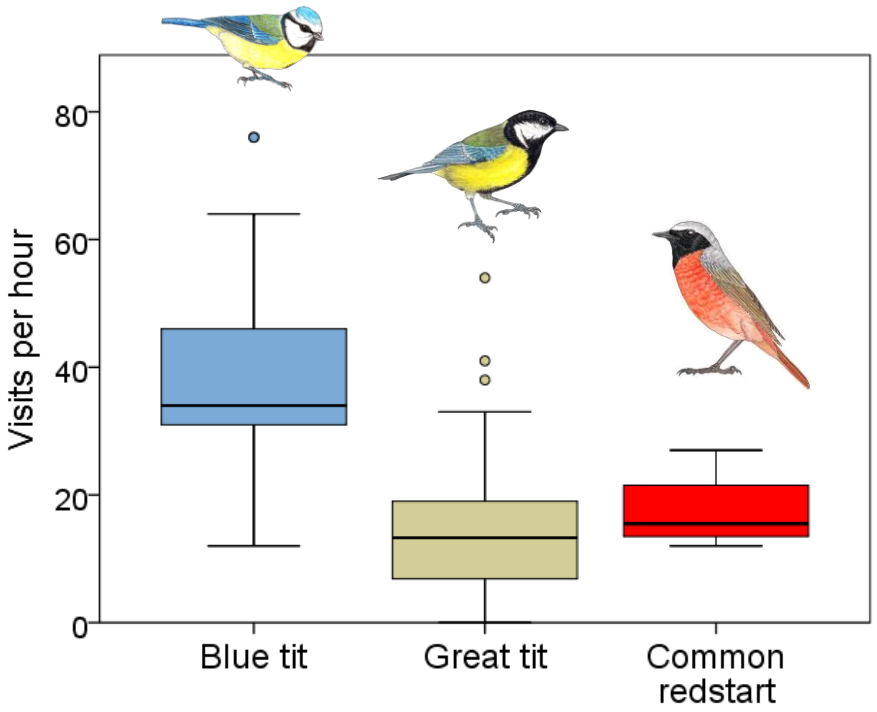

Figure S7. Frequency of feeding visits to the nest (visits per hour) for the three observed bird species. N = 13, 27 and 4 for blue tit, great tit and common redstart, respectively. Artwork by Daniel García.