APPENDIX A

Manuscript Title: Experimental field exclosure of birds and bats in agricultural systems - methodological insights, potential improvements, and cost-benefit trade-offs

APPENDIX TABLES

Table A1: Full references of the 30 studies considered in this review. The study ID refers to the studies listed in Table 1 of our manuscript. Authors from studies 1-18 (feedback studies) provided data on their studies directly. These 18 studies were selected from a litearture search including 125 potentially suitable studies. We considered 12 additional studies in this review (ID 19-30) which were not be detected through the literature search but suggested by the authors of the feedback studies. From these additional studies, we extracted data from the available publications.

<u>For the Google Scholar research, the following keywords and selection criteria were used:</u>

(a) Search terms: “bird*” AND “bat*”, “exclusion” OR “exclosure” AND “agricultur*” OR “agroforest*” OR “farm*” -"wind farm"

(b) Selection criteria: We considered the publication period 2005-2017 and sorted results after “relevance”, excluding patents and citations. The first 100 results were considered (the search yielded 2900 results on 21 October 2017)

ID	Full Reference
1	Kellermann, J. L., Johnson, M. D., Stercho, A. M., & Hackett, S. C. (2008). Ecological and economic services provided by birds on Jamaican Blue Mountain coffee farms. Conservation Biology, *22*(5), 1177-1185.
2	Johnson, M. D., Kellermann, J. L., & Stercho, A. M. (2010). Pest reduction services by birds in shade and sun coffee in Jamaica. Animal Conservation, 13(2), 140-147.
3	Johnson, M. D., Levy, N. J., Kellermann, J. L., & Robinson, D. E. (2009). Effects of shade and bird exclusion on arthropods and leaf damage on coffee farms in Jamaica’s Blue Mountains. Agroforestry Systems, 76(1), 139-148.
4	Williams-Guillén, K., Perfecto, I., & Vandermeer, J. (2008). Bats limit insects in a neotropical agroforestry system. Science, 320(5872), 70-70.
5	Karp, D. S., & Daily, G. C. (2014). Cascading effects of insectivorous birds and bats in tropical coffee plantations. Ecology, 95(4), 1065-1074.
6	Karp, D. S., Mendenhall, C. D., Sandí, R. F., Chaumont, N., Ehrlich, P. R., Hadly, E. A., & Daily, G. C. (2013). Forest bolsters bird abundance, pest control and coffee yield. Ecology Letters, 16(11), 1339-1347.
7	Classen, A., Peters, M. K., Ferger, S. W., Helbig-Bonitz, M., Schmack, J. M., Maassen, G., ... & Steffan-Dewenter, I. (2014). Complementary ecosystem services provided by pest predators and pollinators increase quantity and quality of coffee yields. Proceedings of the Royal Society of London B: Biological Sciences, *281*(1779), 20133148.
8	Martínez-Salinas, A., DeClerck, F., Vierling, K., Vierling, L., Legal, L., Vílchez-Mendoza, S., Avelino, J. (2016). Bird functional diversity supports pest control services in a Costa Rican coffee farm. Agriculture, Ecosystems and Environment, 235, 277-288.
9	Maas, B., Clough, Y., & Tscharntke, T. (2013). Bats and birds increase crop yield in tropical agroforestry landscapes. Ecology Letters, 16(12), 1480-1487.

10	Gras, P., Tscharntke, T., Maas, B., Tjoa, A., Hafsah, A., & Clough, Y. (2016). How ants, birds and bats affect crop yield along shade gradients in tropical cacao agroforestry. Journal of Applied Ecology, 53, 953–963.
11	Cassano, C. R., Silva, R. M., Mariano-Neto, E., Schroth, G., & Faria, D. (2016). Bat and bird exclusion but not shade cover influence arthropod abundance and cocoa leaf consumption in agroforestry landscape in northeast Brazil. Agriculture, Ecosystems & Environment, 232, 247-253.
12	Denmand et al. - in preparation
13	Linden et al. 2015 - in preparation
14	Librán-Embid, F., De Coster, G., & Metzger, J. P. (2017). Effects of bird and bat exclusion on coffee pest control at multiple spatial scales. Landscape Ecology, 32(9), 1907-1920.
15	Kross, S. M., Kelsey, T. R., McColl, C. J., & Townsend, J. M. (2016). Field-scale habitat complexity enhances avian conservation and avian-mediated pest-control services in an intensive agricultural crop. Agriculture, Ecosystems & Environment, 225, 140-149.
16	Heath and Johnson - in preparation (Heat02)
17	Garfinkel, M., & Johnson, M. (2015). Pest-removal services provided by birds on small organic farms in northern California. Agriculture, Ecosystems & Environment, 211, 24-31.
18	Heath and Long - in preparation (Heat01)
19	Gordon, Caleb E., Mcgill, B., Ibarra-nu, G., Greenberg R., Perfecto, I. (2009). Simplification of a coffee foliage-dwelling beetle community under low-shade management. Basic and Applied Ecology 10:246-254
20	Jedlicka, J., Greeberg, R., Perfecto, I., Philpott, S. M., Dietsch, T.V. 2006. Seasonal Shift in the Foraging Niche of a Tropical Avian Resident : Resource Competition at Work? Journal of Tropical Ecology 22(4):385-395
21	Borkhataria, R. R., J. A. Collazo, and M. J. Groom. (2006). Additive effects of vertebrate predators on insects in a Puerto Rican coffee plantation. Ecological Applications 16:696–703.
22	Peters, V. E., & Greenberg, R. (2013). Fruit supplementation affects birds but not arthropod predation by birds in Costa Rican agroforestry systems. Biotropica, 45(1), 102-110.
23	Van Bael, S. A., Bichier, P., & Greenberg, R. (2007). Bird predation on insects reduces damage to the foliage of cocoa trees (Theobroma cacao) in western Panama. Journal of Tropical Ecology, 23(06), 715-719.
24	Koh, L. P. (2008). Birds defend oil palms from herbivorous insects. Ecological Applications, 18(4), 821-825.
25	Ndang'ang'a PK, Njoroge JBM, Vickery J (2013) Quantifying the contribution of birds to the control of arthropod pests on kale, *Brassica oleracea acephala*, a key crop in East African highland farmland. Int J Pest Management 59:211–216
26	Grasswitz, T. R., & James, D. (2011). Phenology and impact of natural enemies associated with the hop looper (*Hypena humuli*) in Washington State, USA. International Journal of Pest Management, 57(4), 329-339.
27	Borkhataria, R.R., Nuessly, G.S., Pearlstine, E., & Cherry, R.H. (2012). Effects of Blackbirds (Agelaius phoenicius) on Stink Bug (Hemiptera: Pentatomidae) Populations, Damage, and Yield in Florida Rice. Florida Entomologist, 95, 143-149.
28	Martin, E. A., Reineking, B., Seo, B., & Steffan-Dewenter, I. (2013). Natural enemy interactions constrain pest control in complex agricultural landscapes. Proceedings of the National Academy of Sciences, 110(14), 5534-5539.
29	Saunders, M.E. & Luck, G.W. (2016) Combining costs and benefits of animal activities to assess net yield outcomes in apple orchards. PLoS One, 11(7).
30	Peisley, R.K., Saunders, M.E., & Luck, G.W. (2016) Cost-benefit trade-offs of bird activity in apple orchards. PeerJ 4:e2179.

Table A2: Extended set of information on studies reported in Table 1. This table shows the mean impact (% change) of bird and bat exclosures on arthropod abundances and crop yield (calculated as % change = (d/a)*100; d = b-a; a = final number of arthropods or amount of yield in control treatments; b= final number of arthropods or amount of yield in combined bird and bat exclosures). All %-change results marked with * indicate studies for which both results for group-specific bird/bat exclosures and results for additionally excluded taxa (e.g., ants, pollinators) are available, and where only the result for combined exclosures is reported. Further, the number of bat and bird exclosure cages (treaments) per site is shown, as well as the number of control treatments per site (open controls not marked; faux controls using frames but no nets marked with *) and the rounded mean size dimensions of each treatment (length x width x height; in m). The table indicates if local management factors (e.g. local shade cover; pesticide management) or landscape management factors (e.g. distance to farm edge, primary forest or adjacent habitats) were considered in the respective study (yes or no). In the last two columns, authors reported the names of arthropod species groups that were considered as main pests or considered as beneficial species groups (contribution to pest control; e.g. mesopredators) in their studies - if available, respective species names are provided in brackets. Empty cells indicate that information were not available or that the respective data were not recorded.

ID	Arthrop. abund. (%)	Crop yield (%)	Cages /site (n)	Controls /site (n)	Treatm. dim. (m)	Local man. (y/n)	Land. man. (y/n)	Main pest species groups	Beneficial species groups
1	60.46	60.46	1	1	2x3x3	yes	yes	Coleoptera (*Hypothenus hampei*)	
2	101.19	101.19	8	8	3x6x3	yes	no	Coleoptera (*Hypothenus hampei*)	
3	195.37		1	1	2x3x3	yes	no	Coleoptera (*Hypothenus hampei*), Aphids, Lepidoptera larvae (*Leucoptera coffeella*)	
4	32.00*		3	1*	1x1x2	no	no	Coleoptera (var), Auchenorryncha, Orthoptera, Lepidoptera (*Leucoptera coffeella*)	Aranae, Hymenoptera/Ants
5	64.50	117.70	3	1*	3x2x2	no	yes	Coleoptera (*Hypothenus hampei*)	Aranae
6	46.89	118.30	1	1*	1x1x2	no	no	Coleoptera (*Hypothenus hampei*)	Aranae
7	71.54	-9.00	1	1	2x2x2	yes	no	Herbivorous and omnivorous arthropods (91 families and 48 species reported)	Aranae, Hymenoptera/Ants
8	81.90		1	1	2x2x3	yes	no	Coleoptera (*Hypothenus hampei*)	
9	223.53	-2.78	3	1	7x5x6	yes	yes	Coleoptera, Lepidoptera (*Conopomorpha cramerella*), Lepidoptera larvae, Blattodea, Orthoptera, Aphids, Miridae (*Helopeltis sulawesii*)	Aranae, Hymenoptera/Ants
10	131.75*	93.36*	6	2	7x5x6	yes	yes	Coleoptera, Lepidoptera (*Conopomorpha cramerella*), Hemiptera (*Helopeltis sulawesii*)	Aranae, Hymenoptera/Ants, Coleoptera, Dermaptera
11	74.00*		12	4		yes	no	Hemiptera, Thysanoptera	Aranae

12	27.00*	38.00*	3	1	16x16x5	no	no	Common oil palm pests - not observed	Aranae
13			3	1*	10x5x5	yes	yes		
14		-5.64	4	4	4x2x2	yes	yes	Coffee-leaf-miner (*Leucoptera coffeella*), coffee-berry-borer (*Hypothanemus hampei*)	Hymenoptera (Vespidae, Braconidae, Eulophidae)
15	50.47		2	2	1x2x1	yes	yes	Coleoptera (*Hypera postica*)	
16	0.86	-16.34	1	1	2x2x3	yes	no	Leaf chewers (Lepidoptera, Pamphiliidae, Tenthredinidae, Disonycha), Suckers/piercers (Auchenorrhyncha,Thysanoptera, Aphididae)	Araneae, Acari, Neuroptera, Reduviidae, Aeolothripidae, Apocrita, Syrphidae
17	-1.12	22.81	1	7	2x1x1	no	no	Lepidoptera larvae & chrysali	
18	64.68		50	50	0.1x 0.1x 0.1	yes	yes	Lepidoptera (*Cydia pomonella*)	Aranae, Perilampidae, Hymenoptera (*Pimpla sanguinipes*, Braconidae), Neuroptera/Chrysopidae
19	-19.20		6 or 10	6 or 10	10x5x3	yes	no	Coleoptera: 42 families, 293 morphospecies	
20	-6.02		1	1	10x5x3	no	no		
21	17.45		1	1		no	no	Lepidoptera (*Leucoptera coffeela*), Hemiptera (*Petrusa epilepsis*)	Aranae, Chrysopidae, Reduviidae
22	48.75		3	3		no	no	Common pests	Araneae
23	84.34		10	10		no	no	Lepidoptera, Coleoptera, Hemiptera, Hymenoptera, Orthoptera	Araneae, Diptera, Hymenopteran wasps
24			1	1	1x1x1	no	no	Lepidoptera (*Setora nitens*, *Metisa plana*, and *Segestes spp*.)	
25	126.32	119.32	9	9	0.5x 0.5 x 0.6	no	no		
26	75.08		5	5	1x1x2	no	no	Lepidoptera (*Hypena humuli*)	Dermaptera, Damsel bug, Geocorid bugs, Parasitoid species (9 spp. reported)
27	-10.63	6.10	1	1	17x17x2	no	no	Hemiptera (*Oebalus spp.*)	
28	-54.05	-11.94	1	1	0.3x0.3 x0.3	yes	yes	Lepidoptera(*Pieris rapae*, *Pieris brassicae*, and *Trichoplusia ni*)	
29		250.00	10	10		yes	no		
30	12.80		10	10		yes	no		

Table A3: Results from a linear mixed-effects model on yield differences of cacao trees following bird and bat exclosure treatments in Indonesian agroforestry, based on data from Maas et al. (2013). The model included the treatment (control, birds excluded, bats excluded, both excluded) as fixed effect. Plantation (N = 15) and yield measurement instance (N = 28) were included as random effects.

Source of variation	**Estimate**	**SE**	**Z**	**P**
(Intercept = control)	0. 176	0. 018	9. 746	<0. 001
Birds excluded	−0. 035	0. 012	−3. 036	0. 002
Bats excluded	−0. 050	0. 012	−4. 276	<0. 001
Both excluded	−0. 062	0. 012	−5. 311	<0. 001

Table A4: Statistical power of the Maas et al. (2013) design to detect an effect of exclosure treatments on cacao yield with a) decreasing number of sampled farms (original design: 15 farms) and b) decreasing amount of yield measurements per cacao tree, treatments and farm (original design: 28 measurements) during the 1-year census. Shown are the resulting statistical power and the lower and upper bounds of 95% confidence intervals (CI).

	Power [%]	95% CI (lower) [%]	95% CI (upper) [%]
a) No of sampled farms			
3	53. 90	50. 75	57. 02
4	66. 70	63. 68	69. 62
6	85. 80	83. 48	87. 91
7	91. 60	89. 71	93. 24
8	94. 20	92. 57	95. 57
10	98. 40	97. 41	99. 08
11	99. 20	98. 43	99. 65
12	99. 40	98. 70	99. 78
14	99. 90	99. 44	100. 00
15	99. 90	99. 44	100. 00
b) No of yield measurements			
3	30. 80	27. 95	33. 76
6	55. 90	52. 76	59. 01
9	76. 70	73. 95	79. 29
11	85. 80	83. 48	87. 91
14	92. 40	90. 58	93. 97
17	96. 70	95. 40	97. 72
20	99. 00	98. 17	99. 52
22	99. 50	98. 84	99. 84
25	99. 80	99. 28	99. 98
28	99. 90	99. 44	100. 00