SUPPLEMENTARY MATERIAL

This document contains supplementary material for the paper:

Socolar & Wilcove (2019) Forest-type specialization strongly predicts avian responses to tropical agriculture. doi:10.1098/rspb.2019.1724

Additional materials (data and R code) are available from Data Dryad. doi:10.5061/dryad.6944855

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Table S1 Summary of parameters included in each model. Filled table cells (black) indicate that the term is included in the model. For ease of coefficient interpretation, continuous predictor variables (foraging stratum, body mass) are standardized. Binary predictors are coded as ones relative to an intercept for non-forest (forest associations), frugivore/nectivore (diet), nonmigratory (migratory), non-limited (river-limited), and non-restricted (fine-scale specialization and range restriction).

			Model					
			global	**habitat**	**traits**	**traits2**	**coarse**	**null**
Intercepts		global	■	■	■	■	■	■
		random (species)	■	■	■	■	■	■
Forest associations		user	■	■	■	■	■	
		specialist	■	■	■	■	■	
Traits	**Foraging stratum**	ground	■		■			
		understory	■		■			
		midstory	■		■			
	Diet	invertebrate	■		■	■		
		omnivore	■		■	■		
		granivore	■		■	■		
		carnivore	■		■	■		
	Body mass		■		■	■		
	Migratory		■		■	■		
Fine-scale specialization and range restriction	**River-limited**		■	■				
	Habitat specialization	floodplain	■	■				
		terra firme	■	■				
		poor soil	■	■				
		rich soil	■	■				

Table S2 Weakly informative prior distributions in all model fits.

Parameter	Prior distribution
intercept	normal(location=0, scale=10)
regression coefficients[a]	normal(location=0, scale=5)
random-effect variance	gamma(shape=1, scale=100)

[a] All independent variables are either centered and scaled (continuous variables) or one-hot encoded (binary and categorical variables).

Table S3 ELPD and R-squared for all model fits.

Model	ELPD (SE)[a]	R-squared[b]
null	-888.3 (27.8)	–
coarse	-818.1 (30.6)	0.34
traits	-797.5 (30.8)	0.41
traits2	-800.3 (31.0)	0.40
habitat	-744.7 (30.7)	0.62
global	-729.4 (30.6)	0.66

[a] The expected log pointwise predictive density, estimated via 10-fold cross validation. SE denotes standard error. Note that the standard errors for the ELPD *difference* between models (not shown, but reflected in figure 2 of the main text) are considerably smaller than the standard errors in the ELPD for a given model (shown here).
[b] R-squared is defined following Nakagawa et al. (2017).

Table S4 Parameter estimates from the global model.

Parameter			**mean**[a]	**lci**[b]	**uci**[c]
Intercepts		global	3.8	2.6	4.9
		random (species)[d]	……not shown……		
Forest associations		user	-0.8	-2.7	1.0
		specialist	-3.1	-4.8	-1.3
Traits	**Foraging stratum**	ground	-0.3	-0.7	0.1
		understory	-0.2	-0.6	0.2
		midstory	-0.5	-0.9	-0.1
	Diet	invertebrate	-1.6	-2.4	-0.9
		omnivore	-0.6	-1.6	0.4
		granivore	0.3	-1.4	2.1
		carnivore	1.8	0.0	3.7
	Body mass		-0.9	-1.4	-0.6
	Migratory		2.6	-0.6	6.6
Fine-scale specialization and range restriction	**River-limited**		-1.1	-2.2	-0.1
	Habitat specialization	floodplain	2.4	1.6	3.1
		terra firme	-1.3	-2.1	-0.5
		poor soil	-3.9	-5.8	-2.1
		rich soil	-.8	-1.7	0

[a] Posterior mean estimate.
[b] Lower bound of posterior 95% credible interval.
[c] Upper bound of posterior 95% credible interval.
[d] The 451 separate random intercept terms for species are not shown here, but are output at the end of the R script associated with the paper (line 803 of Socolar_Wilcove_2019.R).

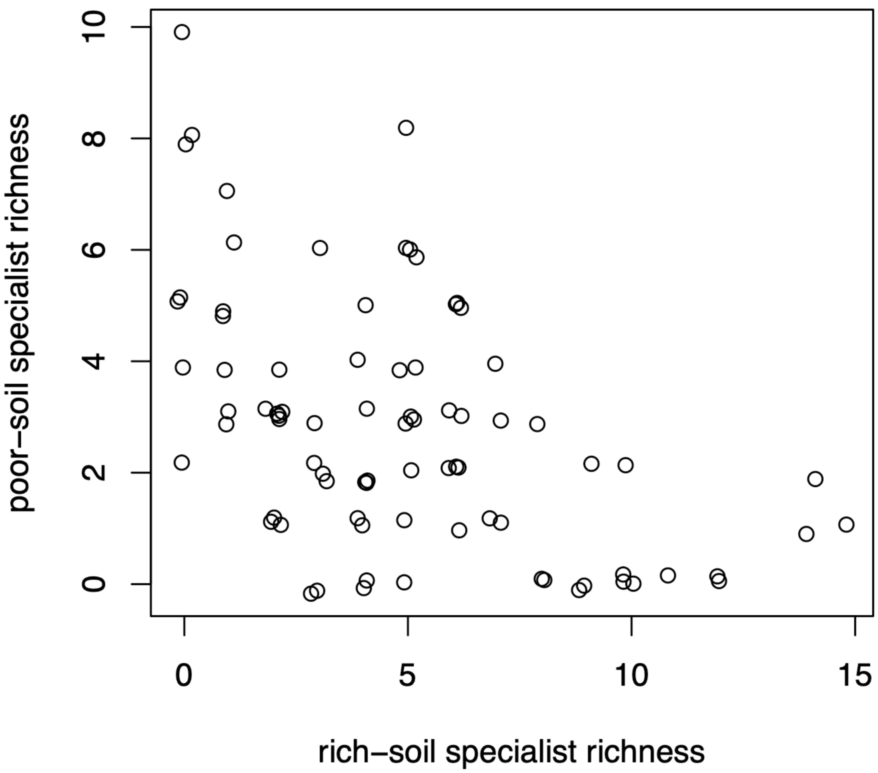

Figure S1 Number of poor-soil versus rich-soil specialists detected at primary-forest *terra firme* points. Points represent individual point-count stations. The number of species detected is an aggregate count across all four visits to a point. To aid in visualizing overlapping points, a small amount of random noise is added to both the x and y coordinates.

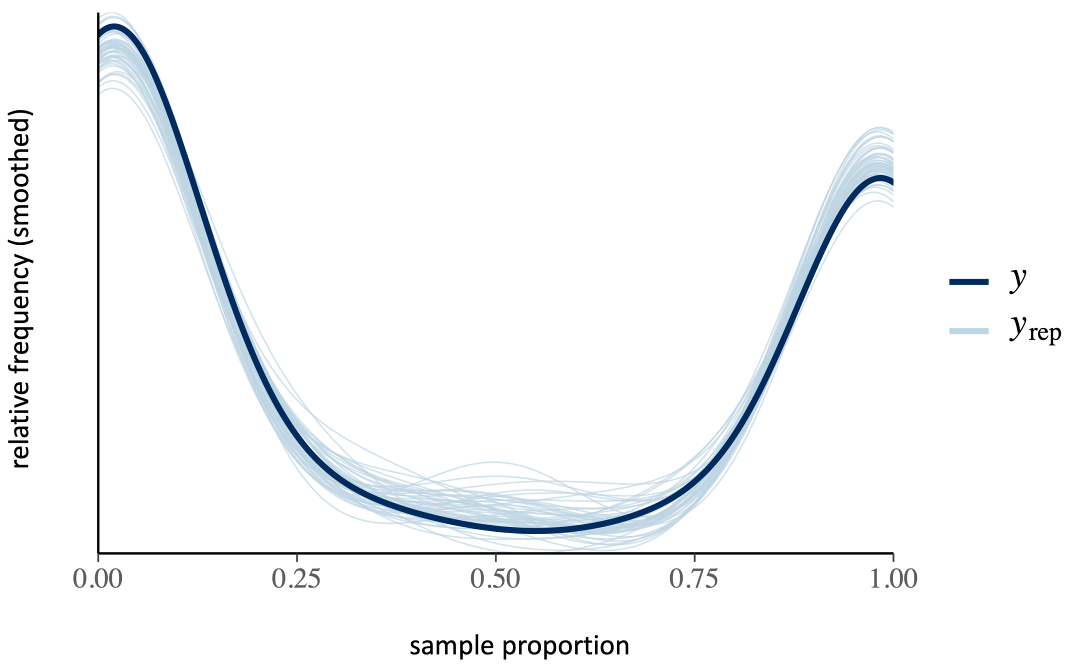

Figure S2 Graphical posterior predictive check for the global model. Kernel density estimators of the frequency distribution of the proportion of successes in the data (black line) and in the posterior predictive distribution from the fitted model (blue lines; each line represents one realization sample from the joint posterior).

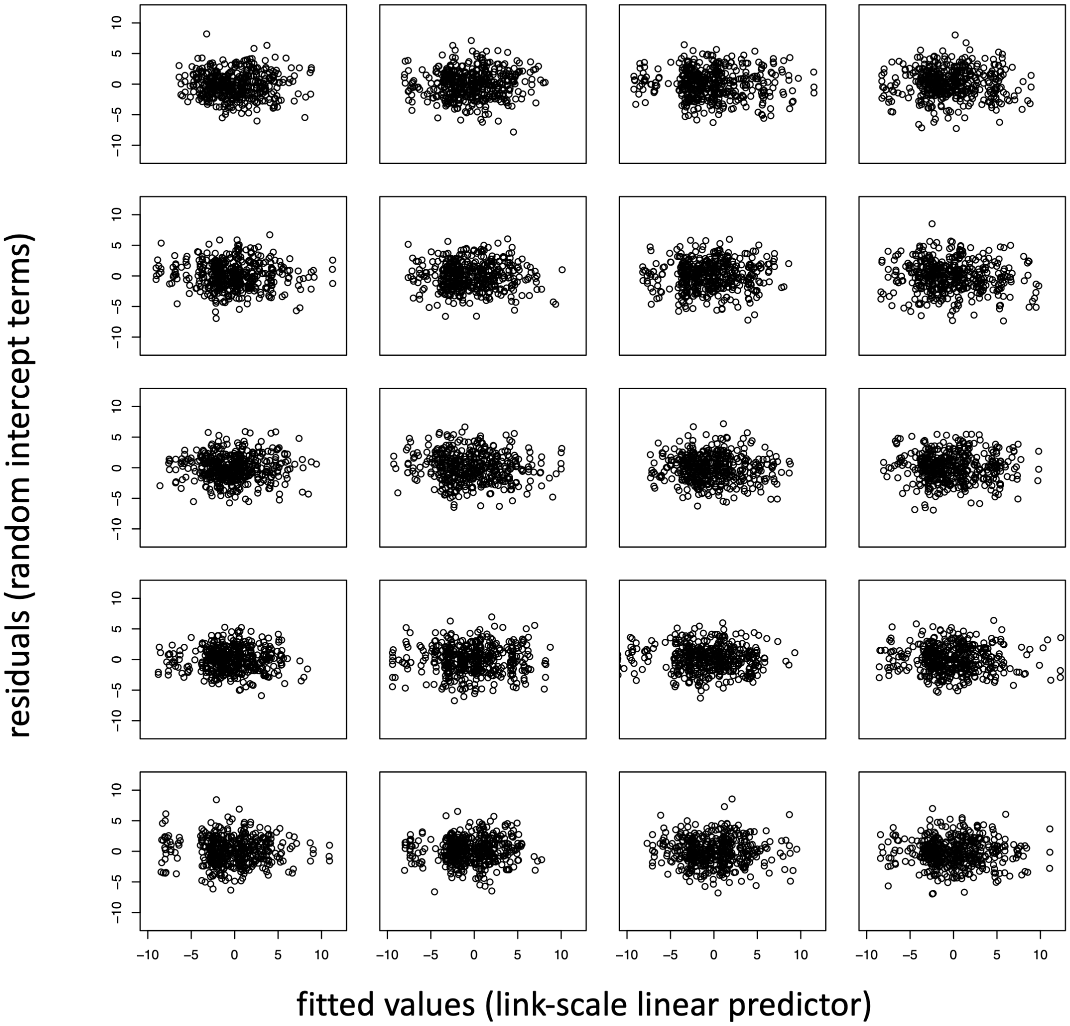

Figure S3 Graphical mixed predictive check for the global model. To check for evidence of misspecification in the hierarchical model component that estimates the latent abundance ratios from covariates, we plot the random effects versus the linear predictor (this is analogous to plotting residuals versus fitted values in linear regression). Each point represents a species, and each plot represents a single iteration of the HMC posterior from (every 200th iteration). The binomial GLMM with a random intercept for species can be thought of as a hierarchical model where the lower level involves binomial sampling from the latent true proportions, and the upper level involves a standard Gaussian linear regression of the (latent) true abundance log-ratios against the covariates. In this latent regression, the residuals correspond to the random intercepts for species in the GLMM. These plots confirm that it is reasonable to model the true abundance log-ratios using a homoscedastic linear model.

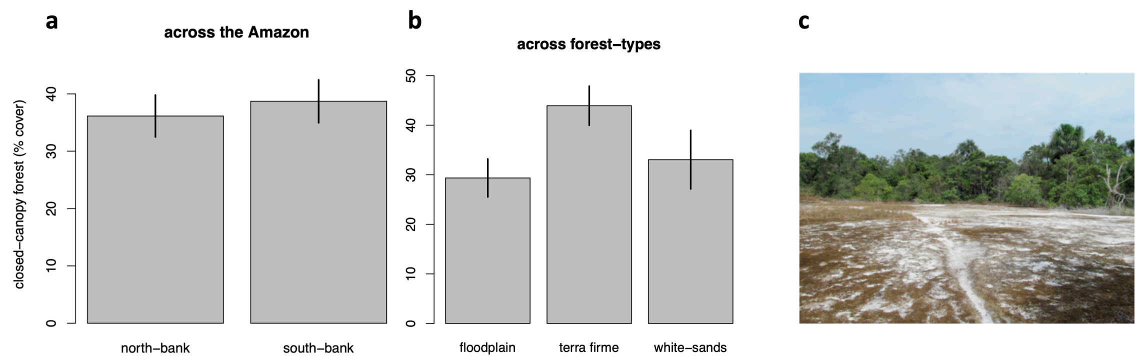

Figure S4 The severity of agricultural disturbance, measured by the percent-cover of secondary forest across the agricultural landscape (normalized by the area at each point that is not open water; i.e. lakes or large rivers). (**a**) Severity does not differ across the Amazon. (**b**) Severity is higher in white-sands than uplands. The difference between floodplain and uplands is difficult to interpret because floodplains naturally have lower closed-canopy forest cover, due primarily to the presence of scrubby or marshy backwater channels. (**c**) The relatively low secondary forest cover in agricultural landscapes might arise due to the glacially slow pace of forest regeneration on poor soils. Pictured is an agricultural plot in white-sands that was abandoned over a decade prior.

APPENDIX S1: Modifications to data sources for habitat specialization

1. Taxonomic standardization

We standardized the taxonomies of Parker, Stotz & Fitzpatrick, 1996 (PSF), Wilman et al., 2014 (EltonTraits), and Socolar, Valderrama & Wilcove, 2019 (SVW) as follows:

1a. Name changes and simple splits

We updated PSF to reflect name changes for species whose name changed due to nomenclatural issues, recent splits where the daughter species present in SVW can be expected to share its habitat preferences with the parent species in PSF, and species in SVW given as subspecies designations in PSF. These changes are hard-coded in lines 47–145 of Socolar_Wilcove_2019.R (doi:10.5061/dryad.6944855).

We also corrected spellings in SVW, and we implemented the split of *Vireo chivi* from *Vireo olivaceus* to correspond to the *Vireo (olivaceus) chivi* subspecies given in PSF. These changes are hard-coded in lines 147–162 of Socolar_Wilcove_2019.R (doi:10.5061/dryad.6944855).

1b. New species and complex splits

The following species are recently described species not present in PSF, or recent splits whose habitat associations meaningfully differ from the associations for the "parent" taxon given in PSF. We obtained their habitat specializations from the literature by consulting with experts including Juan Díaz and Bret Whitney. Their habitat designations are given in parker_additions.csv (doi:10.5061/dryad.6944855).
Percnostola arenarum; *Herpsilochmus gentryi*; *Myrmeciza castanea*; *Xiphorhynchus chunchotambo*; *Sporophila murallae*; *Turdus sanchezorum*; *Icterus croconotus*; *Myrmotherula multostriata*; *Zimmerius villarejoi*; *Herpsilochmus sp. nov.*

2. Changes to habitat associations

Some species have habitat associations in western Amazonia that are mis-classified by Parker et al. (1996). We have amended their classification as follows. All changes were made prior to any data analysis, and no changes were made on the basis of observations in the SVW dataset.

2a. Floodplain specialists

The following species are here classified as floodplain specialists, despite that PSF include non-floodplain habitat associations for these species:

Amazilia fimbriata: PSF include a white-sand habitat association for this species, based on scrubby white sands of eastern Amazonia. In our study area it is absent from white sands and therefore is a floodplain specialist (Alvarez Alonso et al. 2013).

Bartramia longicauda: PSF omit all natural Amazonian habitats for the species, overlooking its regular occurrence on Amazonian river beaches (pers. obs. and eBird data). Unlike the remainder of species in this section, this was mis-classified not because PSF include non-floodplain associations, but rather because PSF omit the floodplain association.

Camptostoma obsoletum: PSF include a white-sand habitat association for this species, based on scrubby white sands of eastern Amazonia. In our study area it is absent from white sands and therefore is a floodplain specialist (Alvarez Alonso et al. 2013).

Cercomacra nigrescens: The population in SVW has recently been split as *C. fuscicauda* and is a strict floodplain specialist (Mayer et al. 2014).

Cnemotriccus fuscatus: PSF include a white-sand association for this species, but this inclusion is based on the white-sand specialist *Cnemotriccus fuscatus duidae*, which is widely understood to be a valid species-level taxon. The records in SVW are referable to subspecies *fuscatior*, a floodplain specialist (Schulenberg et al. 2010).

Cyclarhis gujanensis: This wide-ranging species occurs in other forest types elsewhere but is a strict floodplain specialist in Amazonian Peru (Schulenberg et al. 2010).

Eucometis penicillata: This wide-ranging species occurs in other forest types elsewhere but is a strict floodplain specialist in the western Amazon (Schulenberg et al. 2010).

Hemitriccus minor: The SVW record pertains to subspecies *pallens*, a floodplain specialist (Socolar 2019).

Hylopezus macularius: In Peru, subspecies *dilutus* is restricted to floodplains (pers. obs. and eBird data).

Pachyramphus rufus: This wide-ranging species occurs in other forest types elsewhere but is a strict floodplain specialist in the western Amazon (Schulenberg et al. 2010).

Patagioenas cayennensis: PSF include a white-sand habitat association for this species, based on scrubby white sands of eastern Amazonia. In our study area it is absent from white sands and therefore is a floodplain specialist (Alvarez Alonso et al. 2013).

Sakesphorus canadensis: This wide-ranging species occurs in other forest types elsewhere but is a strict floodplain specialist in the western Amazon (Schulenberg et al. 2010).

Tolmomyias sulphurescens: The western Amazonian population (subspecies *insignis*) is a strict floodplain specialist (Schulenberg & Parker 1997).

Turdus ignobilis: PSF include a white-sand habitat association for this species, but the recently split *Turdus arthuri*, formerly thought to be part of *T. ignobilis*, is a white-sand specialist, and *T. ignobilis* (*sensu stricto*) is generally absent from white sands (Stiles & Avedaño 2019).

Vireo chivi: Records in SVW were of singing individuals in appropriate breeding habitat for the western Amazonian subspecies *solimoensis*, a strict floodplain specialist

(Schulenberg et al. 2010). Therefore, we treat *Vireo chivi* as non-migratory and floodplain-specialist in our analysis.

Xiphorhynchus ocellatus: The western Amazonian subspecies *perplexus* is very poorly known, but is apparently a strict floodplain specialist (Bret Whitney, pers. comm.; pers. obs.; and all known Peruvian records).

2b. Poor-soil specialists

The following three species are here treated as poor-soil specialists, despite that they were not classified that way by either Alvarez Alonso et al. (2013) or Pomara et al. (2012).

Dacnis albiventris: This poorly-known species is infrequently recorded. Peruvian records show a clear pattern of association to poor-soil sites (Socolar et al. 2018).

Percnostola rufifrons: This species (subspecies *jensoni*) has a limited Peruvian distribution that was not well sampled by Alvarez Alonso et al. (2013). It is a poor-soil specialist (Isler et al. 2001).

Xiphorhynchus chunchotambo: This species was recently split from *X. ocellatus*. In Amazonian Peru, the race *napensis* is a poor-soil specialist (pers. obs and eBird data).

2c. Generalists

PSF omit floodplain associations for 44 species in the SVW dataset that unambiguously occur regularly on floodplains, and this results in their mis-classification as *terra firme* specialists. In all cases, the omissions in PSF reflect the incomplete state of knowledge of western Amazonian floodplains in 1996. We remove the *terra firme* specialist classification from these 44 species, which are listed in tf_exclude.csv (doi:10.5061/dryad.6944855).

2d. Species removal

We excluded *Trogon melanurus* and *Hylophylax naevius* from analysis due to the existence of two vocal types within each taxon that apparently segregate by habitat (Pomara et al. 2012, Boesman 2016, ms. in prep Bret Whitney et al.). Including these species in analysis would incorrectly treat habitat specialists as generalists; including the cryptic populations as species-level taxa might be premature and would disclose privileged information that will appear in forthcoming publications authored by other researchers.

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