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Impact of pesticide use on wild bee distributions across the United States

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Supplementary Materials

Impact of pesticide use on wild bee distributions across the United States

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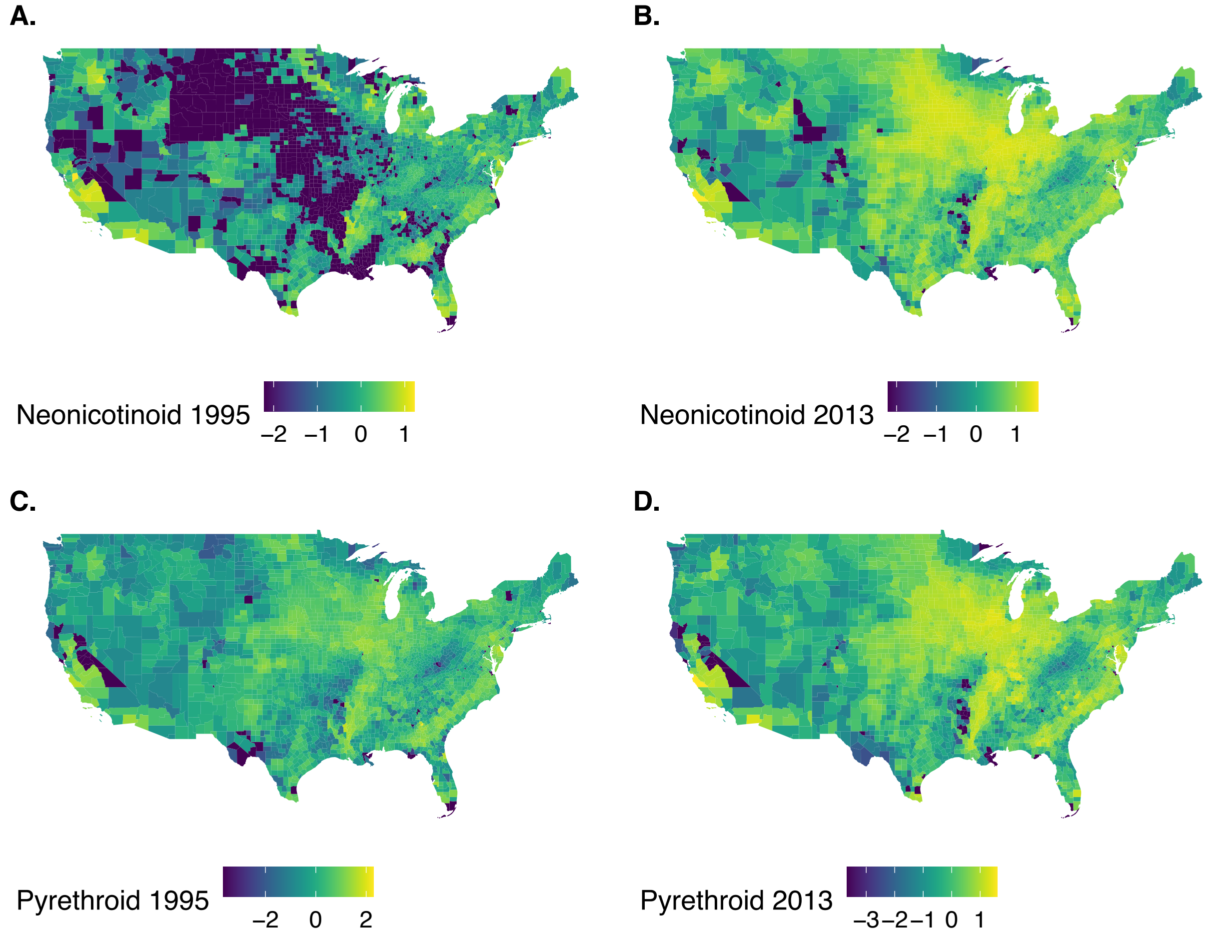

Fig. S1: Neonicotinoids were adopted rapidly across the United States after their introduction in 1995 (A. to B.), while Pyrethroids were widely adopted by 1995 (C. to D.). The color represents the total amount of neonicotinoid applications (log of Kg) at the county level, using the data that was input in the model (see methods for the steps to process pesticide data). Modified from data by [31, 64]

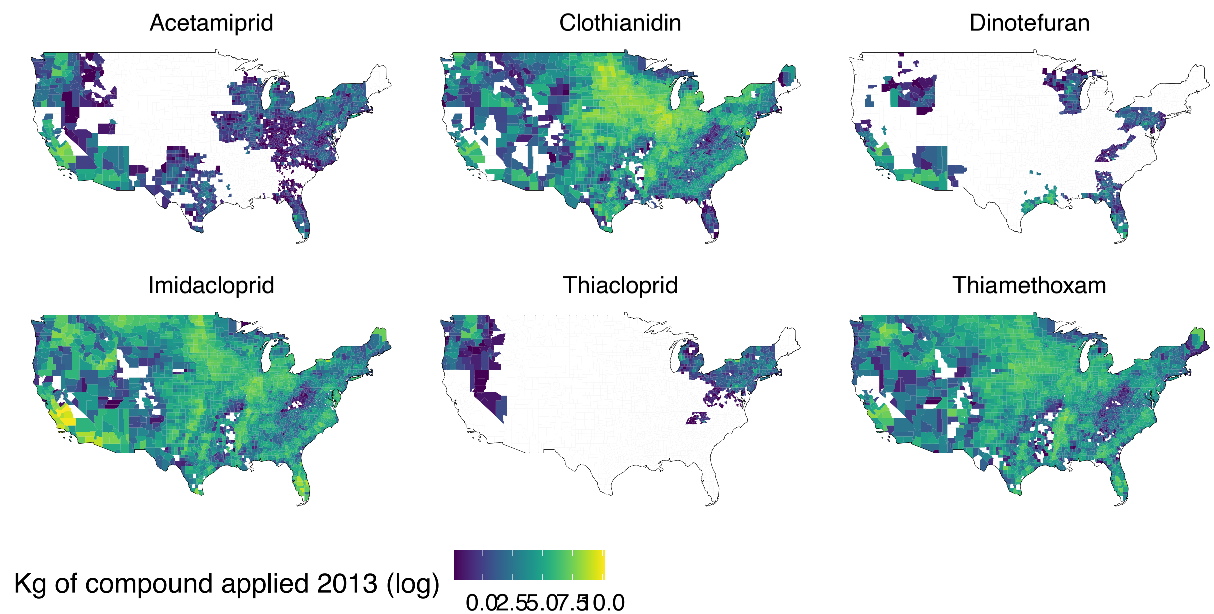

Fig. S2: Individiual neonicotinoids application (log of Kg) at the county level. Modified from data by [64]

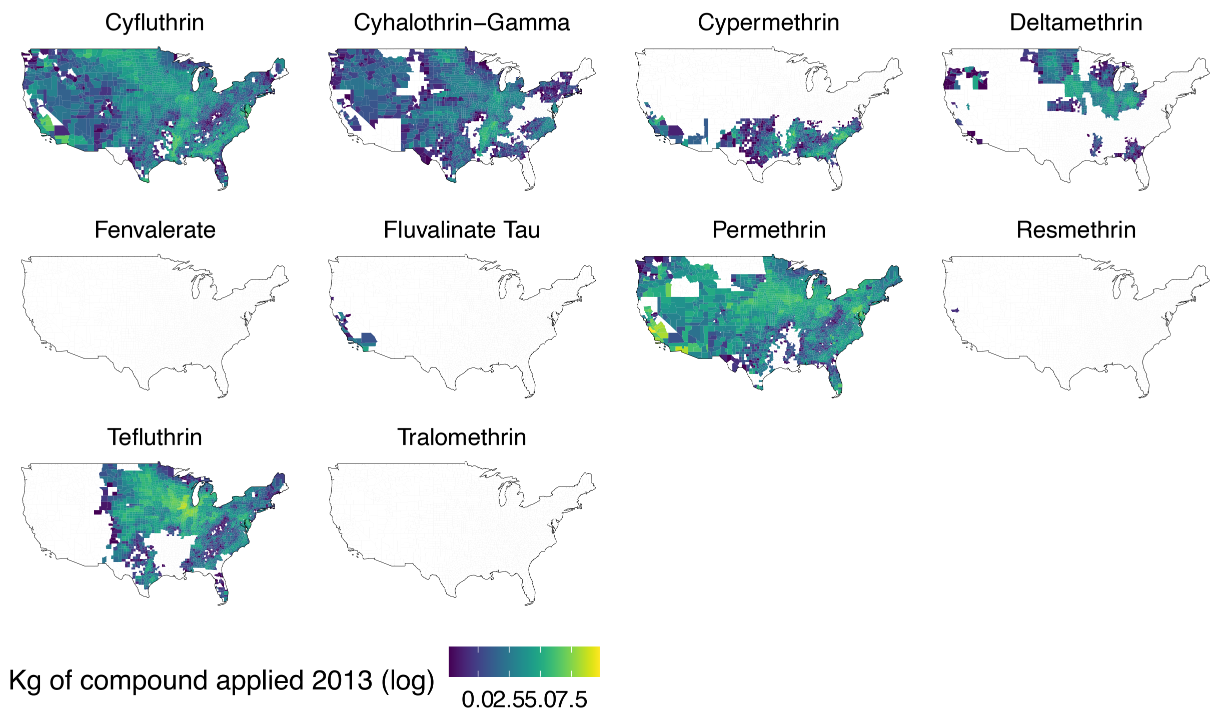

Fig. S3: Individiual pyrethroid application (log of Kg) at the county level. Modified from data by [64]

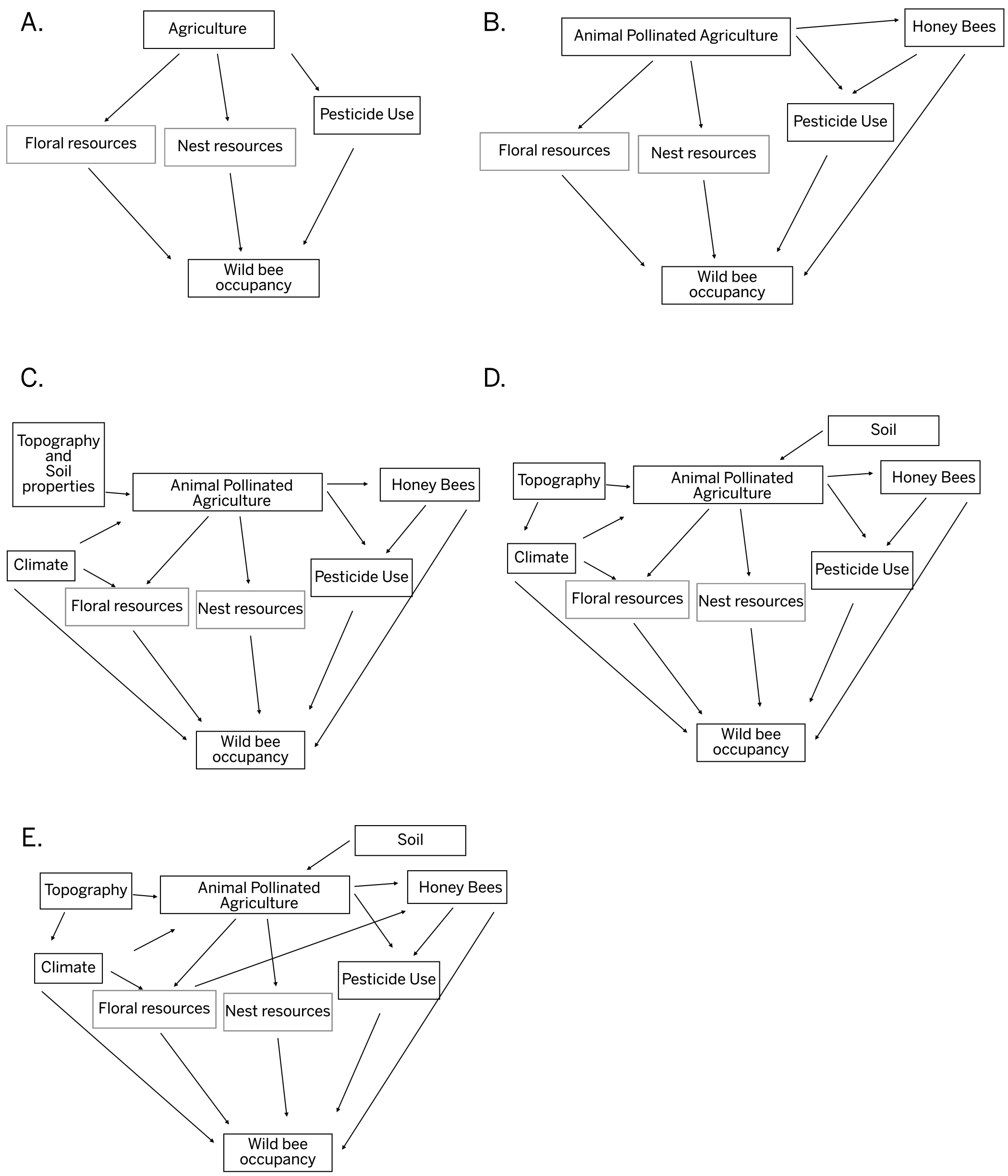

Fig. S4: DAGS provide a visual representation of cause-and-effects relationships of the processes that generate the data. We assume that agriculture that is animal pollinated differs from agriculture that is not animal pollinated because animal pollinated agriculture supplements pollination via honey bees, which may impact the amount of pesticide use. We show progressively the DAGs that were tried based on knowledge of the system and the consistency between the underlying data and the DAGs.

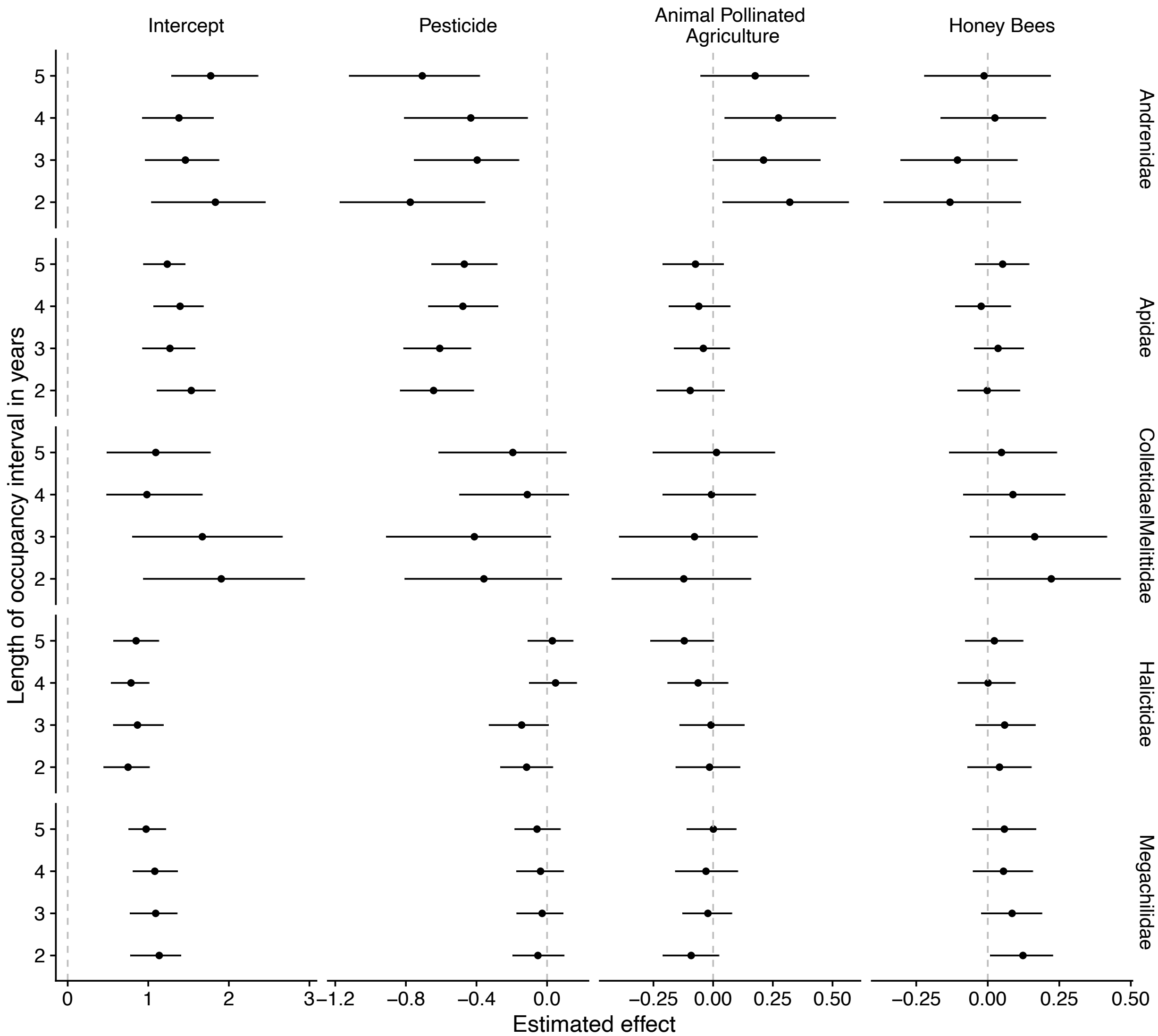

Fig. S5: Sensitivity analysis for model 1 for the number of years that comprise the occupancy interval shows that estimated effects remain similar when occupancy interval is either 2, 3, 4 or 5 years. Visit intervals for all cases remained as 1 year. Grey lines are drawn at zero, estimates are for the mean effect across a family. In this sensitivity analysis the time interval for 3 years was 1995-2015 (21 years total), while the time intervals for 2,4, and 5 years was 1995-2014 (20 years total) to ensure that all time periods had the same number of visits. Error bars represent 95% Bayesian credible intervals. Sample sizes vary for each family but are the same for each model (Extended Data Table 1)

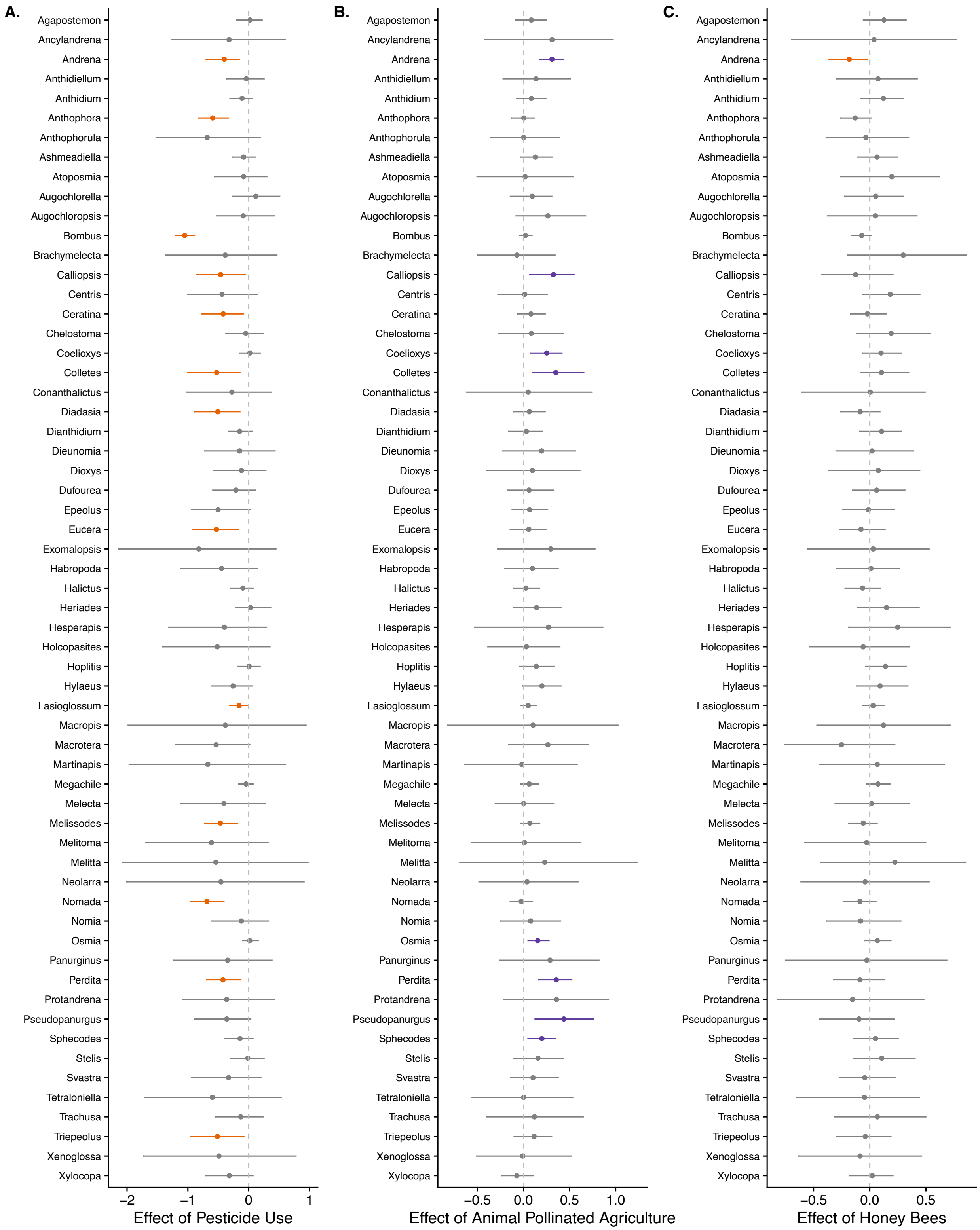
A.
B.
C.
Agapostemon
Ancylandrena
Andrena
Anthidiellum
Anthidium
Anthophora
Anthophorula
Ashmeadiella
Atoposmia
Augochlorella
Augochloropsis
Bombus
Brachymelecta
Calliopsis
Centris
Ceratina
Chelostoma
Coelioxys
Colletes
Conanthalictus
Diadasia
Dianthidium
Dieunomia
Dioxys
Dufourea
Epeolus
Eucera
Exomalopsis
Habropoda
Halictus
Heriades
Hesperapis
Holcopasites
Hoplitis
Hylaeus
Lasioglossum
Macropis
Macrotera
Martinapis
Megachile
Melecta
Melissodes
Melitoma
Melitta
Neolarra
Nomada
Nomia
Osmia
Panurginus
Perdita
Protandrena
Pseudopanurgus
Sphecodes
Stelis
Svastra
Tetraloniella
Trachusa
Triepeolus
Xenoglossa
Xylocopa
−2
−1
0
1
Effect of Pesticide Use
−0.5
0.0
0.5
1.0
Effect of Animal Pollinated Agriculture
−0.5
0.0
0.5
Effect of Honey Bees

Fig. S6: Genus-level effect sizes for all genera in our data-set; the mean effect the effect of pesticide use is strongly negative across all genera (A., Model 1), the mean effect of animal pollinated agriculture is largely positive (B. Model 2), the mean effect of honey bees is mixed across genera (C. Model 3). Grey points and bars represent credible intervals at the genus level that overlap zero, blue points and bars represent credible intervals that do not overlap zero and are positive, and orange points and bars represent credible intervals that do not overlap zero and are negative. Points represent means and error bars represent 95% Bayesian credible intervals. Sample sizes vary for each family but are the same for each model (Extended Data Table 1).

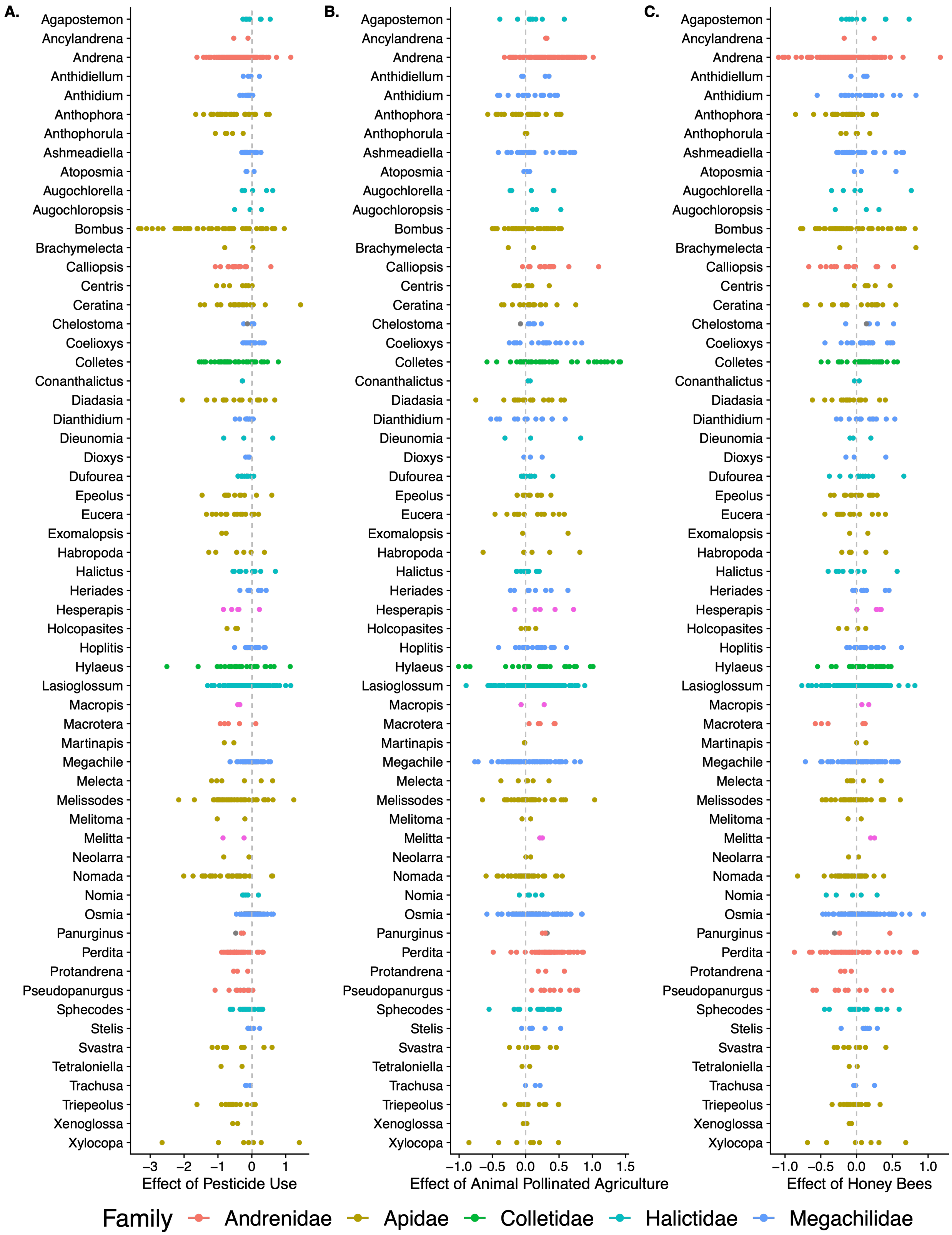
A.
B.
C.
Agapostemon
Ancylandrena
Andrena
Anthidiellum
Anthidium
Anthophora
Anthophorula
Ashmeadiella
Atoposmia
Augochlorella
Augochloropsis
Bombus
Brachymelecta
Calliopsis
Centris
Ceratina
Chelostoma
Coelioxys
Colletes
Conanthalictus
Diadasia
Dianthidium
Dieunomia
Dioxys
Dufourea
Epeolus
Eucera
Exomalopsis
Habropoda
Halictus
Heriades
Hesperapis
Holcopasites
Hoplitis
Hylaeus
Lasioglossum
Macropis
Macrotera
Martinapis
Megachile
Melecta
Melissodes
Melitoma
Melitta
Neolarra
Nomada
Nomia
Osmia
Panurginus
Perdita
Protandrena
Pseudopanurgus
Sphecodes
Stelis
Svastra
Tetraloniella
Trachusa
Triepeolus
Xenoglossa
Xylocopa
Effect of Pesticide Use
Effect of Animal Pollinated Agriculture
Effect of Honey Bees
Family
Andrenidae
Apidae
Colletidae
Halictidae
Megachilidae

Fig. S7: The effect for each of the genera is calculated from the species specific effects modelled. Here we present the distribution of mean species specific effects for each genera for the mean effect of pesticide use (A., Model 1), animal pollinated agriculture (B. Model 2), and the mean effect of honey bees (C. Model 3).

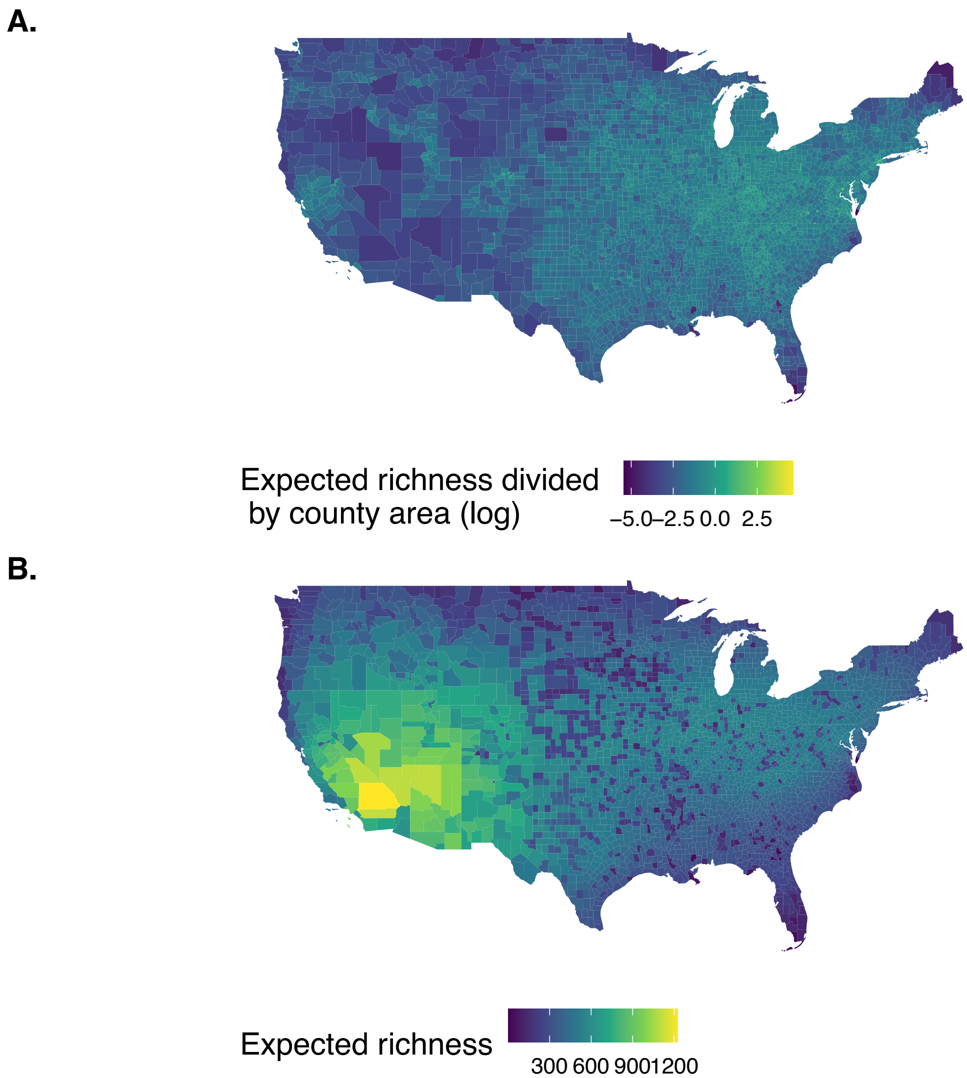

Fig. S8: Expected richness across the United States differs depending on whether we control for county size A. or present simply raw expected richness per county B. Wild bee expected richness was compiled from [25].

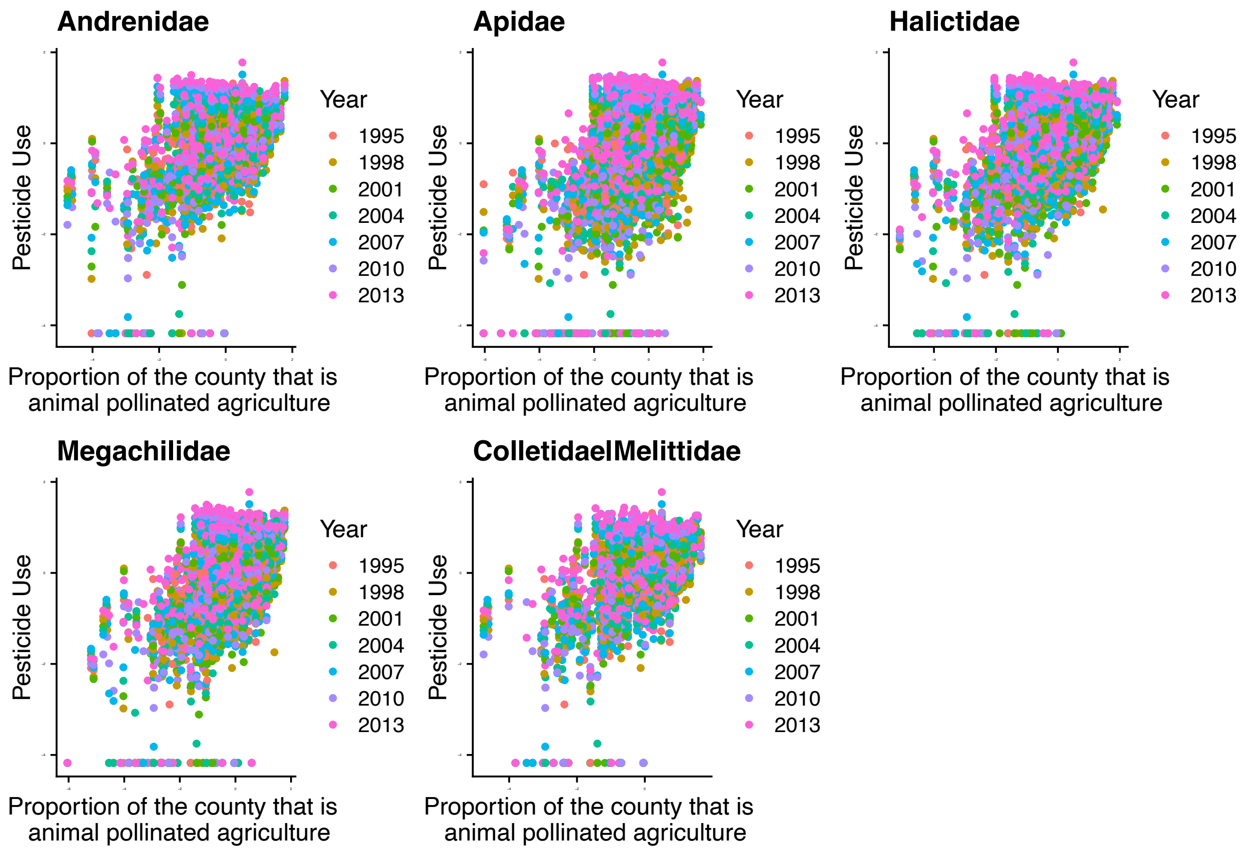

Fig. S9: Correlation between pesticide use and the proportion of the county that is animal pollinated agriculture. The correlation ranged between 0.49 and 0.61. The correlation is calculated for every family because each family was modelled over a different set of counties (Extended Data Fig. 8).

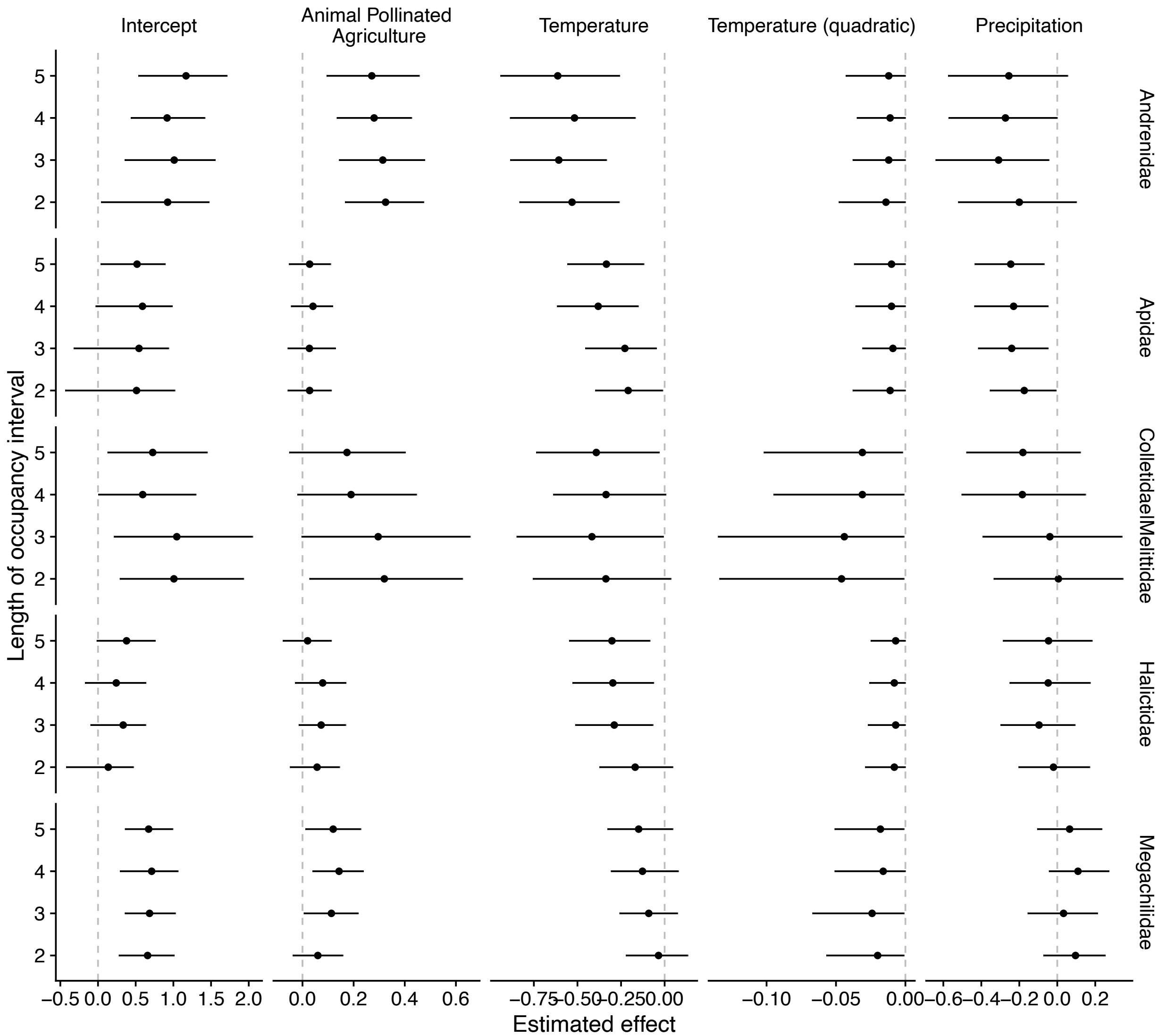

Fig. S10: Sensitivity analysis for model 2 for the number of years that comprise the occupancy interval shows that estimated effects remain similar when occupancy interval is either 2, 3, 4 or 5 years. Visit intervals for all cases remained as 1 year. Grey lines are drawn at zero, estimates are for the mean effect across a family. In this sensitivity analysis the time interval for 3 years was 1995-2015 (21 years total), while the time intervals for 2,4, and 5 years was 1995-2014 (20 years total) to ensure that all time periods had the same number of visits. Error bars represent 95% Bayesian credible intervals. Sample sizes vary for each family but are the same for each model (Extended Data Table 1).

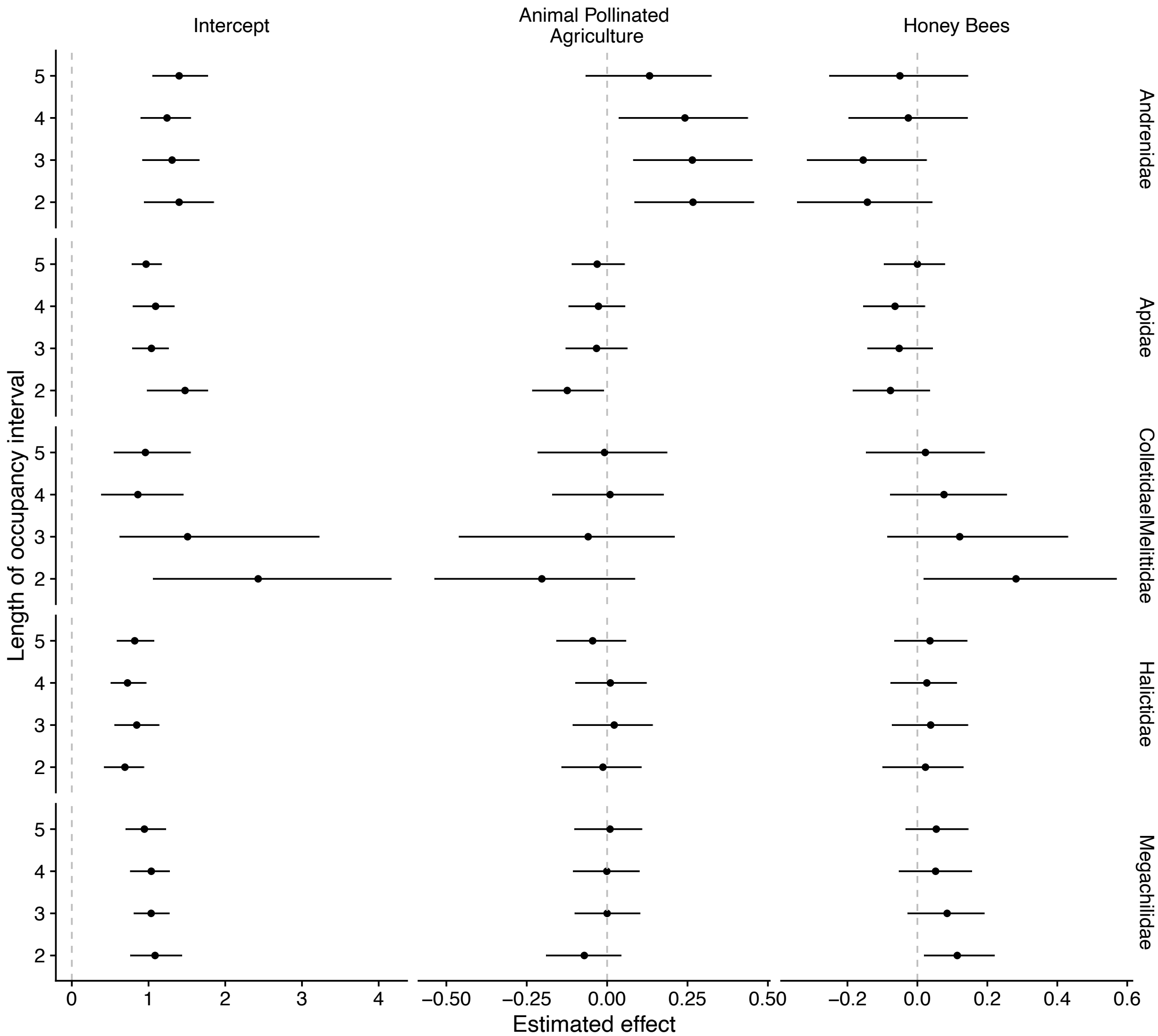

Fig. S11: Sensitivity analysis for model 3 for the number of years that comprise the occupancy interval shows that estimated effects remain similar when occupancy interval is either 2, 3, 4 or 5 years. Visit intervals for all cases remained as 1 year. Grey lines are drawn at zero, estimates are for the mean effect across a family. In this sensitivity analysis the time interval for 3 years was 1995-2015 (21 years total), while the time intervals for 2,4, and 5 years was 1995-2014 (20 years total) to ensure that all time periods had the same number of visits. Error bars represent 95% Bayesian credible intervals. Sample sizes vary for each family but are the same for each model (Extended Data Table 1).

Compound	Mean LD50 (ng/bee)
Neonicotiniods	
Imidacloprid	59.6
Thiamethoxam	101
Acetamiprid	8382
Clothianidin	35.5
Thiacloprid	56330
Dinotefuran	34.7
Pyrethroids	
Cyfluthrin	36.4
Cypermethrin	190
Permethrin	53.00
Tefluthrin	170.00
Tralomethrin	90.50
Fenvalerate	6.3
Deltamethrin	16159
Cyhalothrin-Gamma	18.0
Resmethrin	49.8
Fluvalinate Tau	12433

Table S1: Mean contact acute LD50 (dose where half of the individuals die) for all pesticides evaluated. The lower the LD50 the higher the toxicity of the compounds.