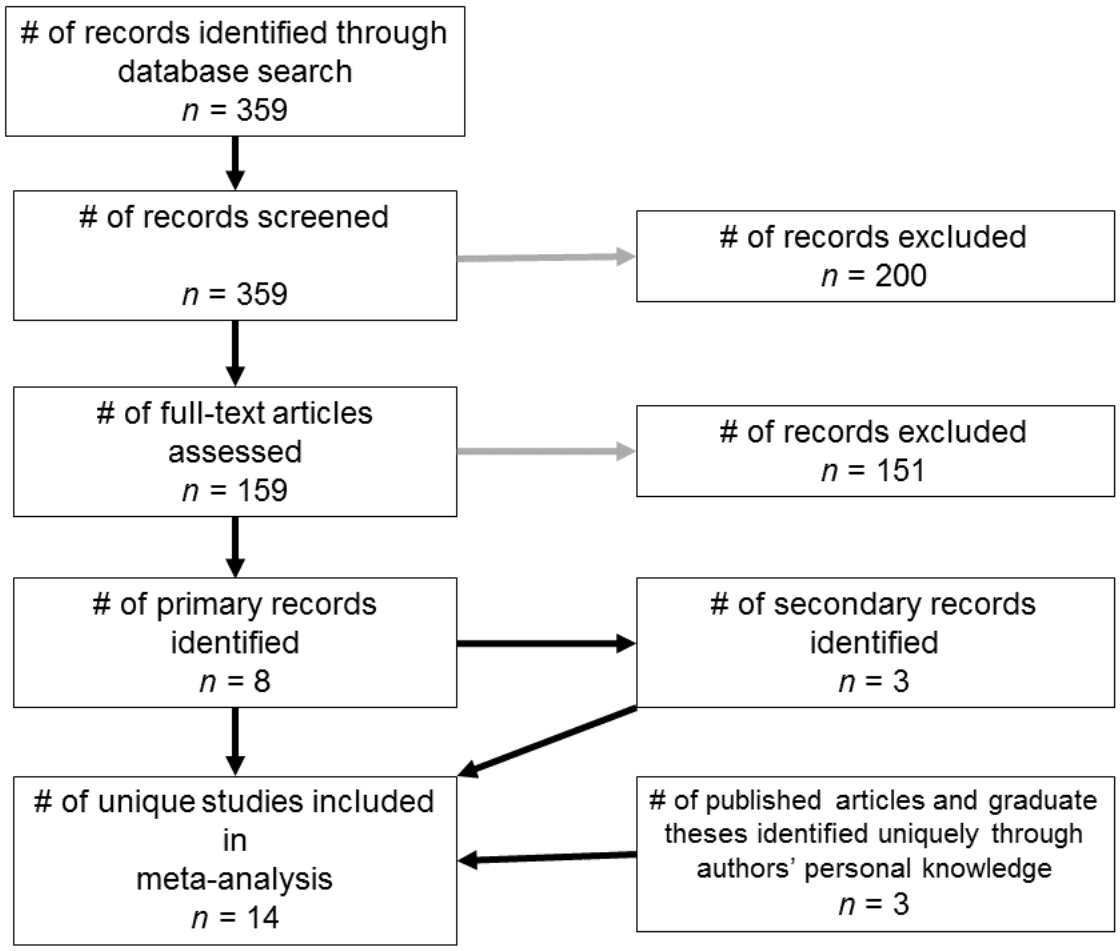
Supplementary Information

Appendix S1. PRISMA diagram



Appendix S2. References of studies included in meta-analysis

1. Beauséjour, R., I. T. Handa, M. J. Lechowicz, B. Gilbert, and M. Vellend. 2014. Historical anthropogenic disturbances influence patterns of non-native earthworm and plant invasions in a temperate primary forest. *Biological Invasions* 17:1267–1281.

2. Choi, A. 2012. Invasive Earthworm (Oligochaeta: Lumbricidae) Populations in varying Vegetation Types on a Landscape-and Local-scale. Thesis, University of Toronto.

3. Corio, K., A. Wolf, M. Draney, and G. Fewless. 2009. Exotic earthworms of great lakes forests: A search for indicator plant species in maple forests. *Forest Ecology and Management* 258:1059–1066.

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7. Hopfensperger, K. N., and S. Hamilton. 2015. Earthworm Communities in Previously Glaciated and Unglaciated Eastern Deciduous Forests. *Southeastern Naturalist* 14:66–84.

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10. Nuzzo, V. A., J. C. Maerz, and B. Blossey. 2009. Earthworm invasion as the driving force behind plant invasion and community change in northeastern North American forests. *Conservation Biology* 23:966–974.

11. Ojanen, P. T. 2014. A study of herbaceous vegetation in Chequamegon - Nicolet National Forest: relationship of earthworms, white-tailed deer browsing and Carex pensylvanica Lam. University of Minnesota.

12. Scharenbroch, B. C., B. Nix, K. A. Jacobs, and M. L. Bowles. 2012. Two decades of low-severity prescribed fire increases soil nutrient availability in a Midwestern, USA oak (*Quercus*) forest. Geoderma 183–184:80 – 91.

13. Straube, D., E. A. Johnson, D. Parkinson, S. Scheu, and N. Eisenhauer. 2009. Nonlinearity of effects of invasive ecosystem engineers on abiotic soil properties and soil biota. *Oikos* 118:885–896.

14. Umek L. and L. Heneghan, unpublished data.

Appendix S3. Metadata of "Cravenetal_EffectSizes_Earthworms_PlantDiversity.csv"

Study. Unique identifier for each study, corresponding 'Study Name' in SI Table 1.

Site. Unique identifier for each site within each study.

Plot_N. Number of locations per site per study where measures of both plant and non-native earthworm communities were taken.

Plant Diversity Measure. Identifier of measure used to assess species diversity of plant communities: 'SppNum' is species number, 'SppDiv' is Shannon-Weiner diversity, 'SppEven' is species evenness (Evar ; Smith & Wilson 1996), and 'Total_Cover" is total plant cover, i.e. the sum of plant cover per species.

Non-native Earthworm Community Measure. Identifier of measure used to assess non-native earthworm communities: 'Biomass' is total biomass of non-native earthworms, 'Density' is total density of non-native earthworms, and 'EEG_Richness' is earthworm ecological groups richness of non-native earthworms, i.e. the number of earthworm ecological groups (epigeic, endogeic, and anecic).

Z-score. Value of Fisher's z transformation of *r* (Pearson's correlation) for used for analysis to normalize the distribution of data. Each value represents the magnitude and direction of the correlation between the corresponding measure of plant and non-native earthworm communities.

Variance. Variance is an unbiased estimate of sampling variance (Hedges 1989) calculated using a large sample approximation.

File Name: "Cravenetal_EffectSizes_Earthworms_PlantDiversity.csv"

Appendix S4. Metadata of "Cravenetal_EffectSizes_Earthworms_PlantFunctGroups.csv"

Study. Unique identifier for each study, corresponding 'Study Name' in SI Table 1.

Site. Unique identifier for each site within each study.

Plot_N. Number of locations per site per study where measures of both plant and non-native earthworm communities were taken.

Plant Functional Group or Native Status. Identifier of plant functional group or native /non-native status: "Forb_herb" are herbaceous plants that are not graminoids, "Graminoid" are grasses or sedges, and "Woody" are plant species that produce wood (e.g., trees, shrubs, or vines), 'Native' are species classified as native to North America, and 'Introduced' are plant species classified as non-native to North America (USDA Plants Database).

Non-native Earthworm Community Measure. Measure of non-native earthworm communities: 'Biomass' is total biomass of non-native earthworms, 'Density' is total density of non-native earthworms, and 'EEG_Richness' is earthworm ecological groups richness of non-native earthworms, i.e. the number of earthworm ecological groups (epigeic, endogeic, and anecic) present in a given plot.

Z-score. Value of Fisher's z transformation of *r* (Pearson's correlation) for used for analysis to normalize the distribution of data. Each value represents the magnitude and direction of the correlation between the corresponding measure of plant and non-native earthworm communities.

Variance. Variance is an unbiased estimate of sampling variance (Hedges 1989) calculated using a large sample approximation.

File Name: "Cravenetal_EffectSizes_Earthworms_PlantFunctGroups.csv"

Table S1. Studies included in meta-analysis and information about publication type, the data used, earthworm extraction technique, earthworm plot location (relative to vegetation plots), earthworm community descriptors, plant community descriptions, the number of plots, study years, and study location.

Study	Publication type	Data	Earthworm extraction method	Earthworm plot location	Earthworm variables	Earthworm Sampling (#/year)	Plant Variables	Plots (#)	Years	Location
Beausejour	Article	Raw	Liquid mustard	Nested	Biomass, EEG Richness	1	Diversity, PFG Abundance, Native Status	85	2011	Quebec, Canada
Choi	Thesis	Raw	Liquid mustard	Nested	Biomass, Density, EEG Richness	1	Diversity	16	2011	Ontario, Canada
Corio	Article	Extracted	Liquid mustard	Adjacent	Biomass	1	Diversity	60	2005	Wisconsin, USA
Eisenhauer	Article	Raw	Hand-sorting, Formalin	Nested	Biomass, Density, EEG Richness	1	Diversity, PFG Abundance, Native Status	30	2004	Alberta, Canada
Gibson	Article	Raw	Hand-sorting, Liquid mustard	Nested	Density, EEG Richness	2	Diversity, PFG Abundance, Native Status	24	2010	Indiana, USA
Hale	Article	Extracted	Liquid mustard	Nested	Biomass	1	Diversity	180	1998 – 2001	Minnesota, USA
Hopfensperger A	Article	Raw	Formalin	Adjacent	Density, EEG Richness	1	Diversity, PFG Abundance, Native Status	10	2001 – 2008	New York, USA
Hopfensperger B	Article	Raw	Liquid mustard	Nested	Density, EEG Richness	1	Diversity, PFG Abundance, Native Status	72	2011	Ohio & Kentucky, USA
Loss	Article	Raw	Liquid mustard	Nested	Biomass, Density, EEG Richness	1	PFG Abundance	270	2009 – 2010	Minnesota & Wisconsin, USA
Nuzzo	Article	Raw	Coverboards	Adjacent	Biomass, EEG Richness	8 – 14	Diversity, PFG Abundance, Native Status	437	2000 – 2002	New York & Pennsylvania, USA
Ojanen	Thesis	Raw	Liquid mustard, Midden counts	Nested	EEG Richness	1	Diversity, PFG Abundance, Native Status	61	2009 – 2010	Wisconsin, USA
Scharenbroch	Article	Raw	Hand-sorting, Liquid mustard	Nested	Biomass, Density, EEG Richness	1	Diversity, PFG Abundance, Native Status	40	2008	Illinois, USA

Study	Publication type	Data	Earthworm extraction method	Earthworm plot location	Earthworm variables	Earthworm Sampling (#/year)	Plant Variables	Plots (#)	Years	Location
Straube	Article	Raw	Hand-sorting, Formalin	Nested	Biomass, Density, EEG Richness	1	Diversity, PFG Abundance, Native Status	30	2007	Alberta, Canada
Umek	Thesis	Raw	Liquid mustard	Nested	Biomass, Density, EEG Richness	1	Diversity, PFG Abundance	29	2009 – 2010	Illinois, USA

Diversity of plant communities was quantified using the following measures: species richness, Shannon-Weiner diversity, and evenness (Evar; Smith and Wilson 1996). EEG Richness is the earthworm ecological group richness. PFG abundance is plant functional group abundance of grasses, woody, and herbaceous plant species; and native status is the abundance of native or non-native plants.

Table S2. Introduced earthworm species and their corresponding ecological groups used in the present study

Genus	Species	Life Stage	Earthworm Ecological Group
Allobophora	*spp.*	Adult	endogeic
Allobophora	*spp.*	Juvenile	-
Aporrectodea	*calignosa*	Adult	endogeic
Aporrectodea	*calignosa*	Juvenile	-
Aporrectodea	*chlorotica*	Adult	endogeic
Aporrectodea	*chlorotica*	Juvenile	-
Aporrectodea	*longa*	Adult	anecic
Aporrectodea	*longa*	Juvenile	-
Aporrectodea	*rosea*	Adult	endogeic
Aporrectodea	*rosea*	Juvenile	-
Aporrectodea	*spp.*	Adult	endogeic
Aporrectodea	*spp.*	Juvenile	-
Aporrectodea	*trapezoides*	Adult	endogeic
Aporrectodea	*trapezoides*	Juvenile	-
Aporrectodea	*tuberculata*	Adult	endogeic
Aporrectodea	*tuberculata*	Juvenile	-
Aporrectodea	*turgida*	Adult	endogeic
Aporrectodea	*turgida*	Juvenile	-
Dendrobaena	*octaedra*	Adult	epigeic
Dendrobaena	*octaedra*	Juvenile	-
Dendrobaena	*rubida*	Adult	epigeic
Dendrobaena	*rubida*	Juvenile	-
Dendrodrilus	*rubidus*	Adult	epigeic
Dendrodrilus	*rubidus*	Juvenile	-
Eiseniella	*tetraedra*	Adult	epigeic
Eiseniella	*tetraedra*	Juvenile	-
Lumbricus	*castaneus*	Adult	epigeic
Lumbricus	*castaneus*	Juvenile	-
Lumbricus	*rubellus*	Adult	epigeic
Lumbricus	*rubellus*	Juvenile	-
Lumbricus	*spp.*	Adult	-
Lumbricus	*spp.*	Juvenile	epigeic
Lumbricus	*terrestris*	Adult	anecic
Lumbricus	*terrestris*	Juvenile	-
Octolasion	*spp.*	Adult	-
Octolasion	*spp.*	Juvenile	endogeic
Octolasion	*tyrtaeum*	Adult	endogeic
Octolasion	*tyrtaeum*	Juvenile	-

Sims and Gerard (1985) and Coleman and Crossley Jr (2004) were consulted to determine earthworm ecological groups for earthworm species.

Table S2 (continued)

References

Sims, R. W., and B. M. Gerard. 1985. Earthworms: keys and notes for the identification and study of the species. Brill Archive.

Coleman, D. C., and D. A. Crossley Jr. 2004. Fundamentals of soil ecology. Academic press.

Table S3. Summary of meta-analytic mixed-effects models testing the relationships between introduced earthworm biomass, density, and ecological group richness in forest understory communities in North America.

Response variable	Study	Observations	AICc	Residual heterogeneity	*L*
Combinations of earthworm community measures	11	79	130.47	***714.1***	***25.4***

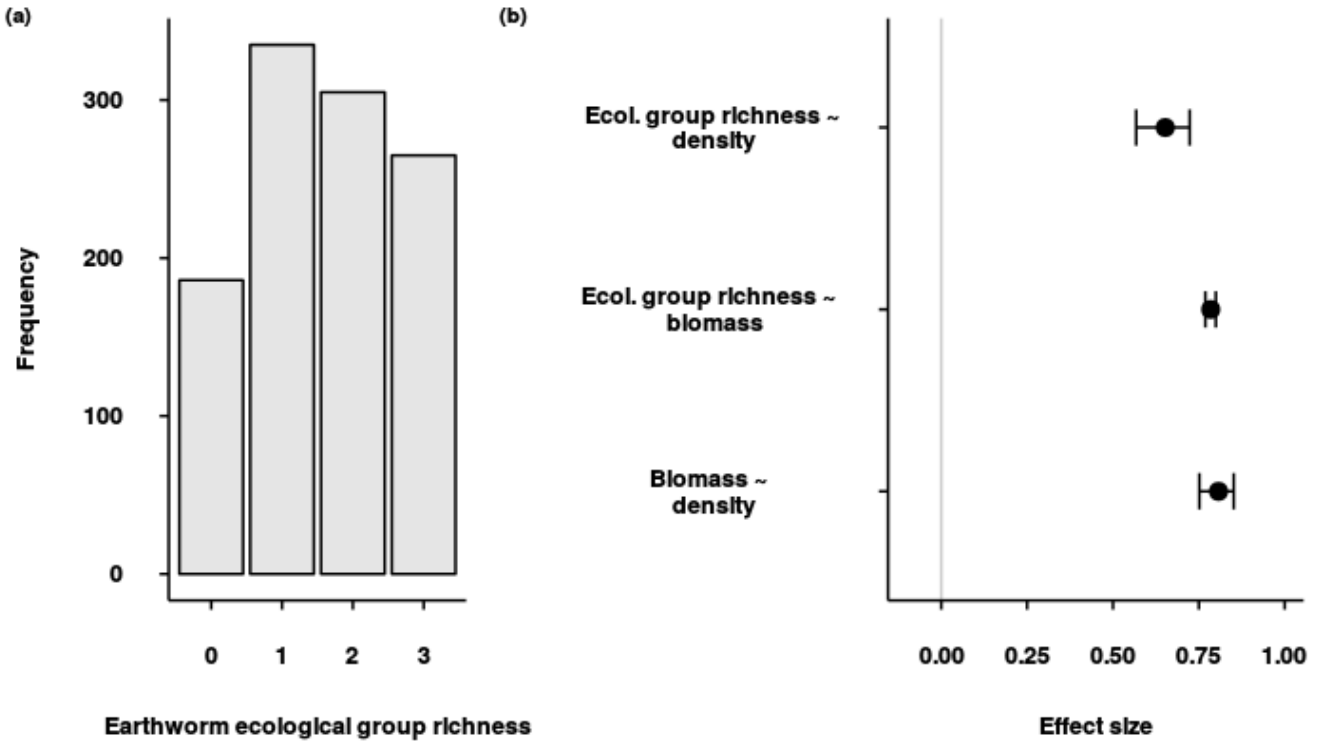
Meta-analytic mixed-effects models evaluated the direction and strength of size effects representing the association between unique combinations of measures of introduced earthworm community abundance or structure (density, biomass, earthworm ecological group richness).Residual heterogeneity shows if the variability of the effect sizes not captured by the moderator variables is heterogeneous. The moderator variables in all models were measures of introduced earthworm communities. L is the likelihood ratio test statistic for model coefficients. Values of residual heterogeneity and L in black italics indicate statistical significance ($\alpha = 0.05$). Please see Figure A1 for mean effect sizes.

Table S4. Summary of meta-analytic mixed-effects models testing the relationships between introduced earthworm biomass, density, and ecological group richness and total plant cover in forest understory communities in North America.

Response variable	Study	Observations	AICc	Residual heterogeneity	*L*
Total plant cover	10	75	38.94	***119.3***	1.3

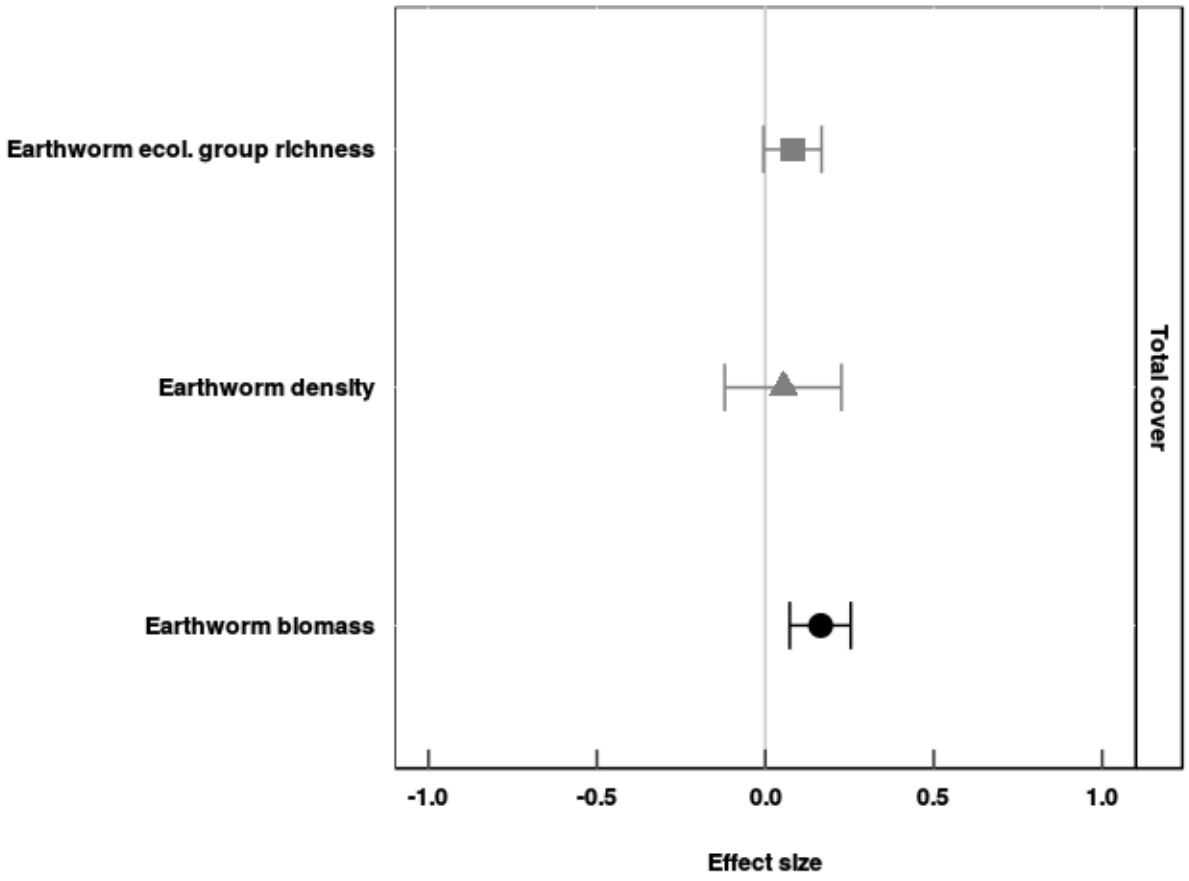
Meta-analytic mixed-effects models evaluated the direction and strength of size effects representing the association between a measure of introduced earthworm community abundance or structure (density, biomass, earthworm ecological group richness) and total plant cover (%). Residual heterogeneity shows if the variability of the effect sizes not captured by the moderator variables is heterogeneous. The moderator variables in all models were measures of introduced earthworm communities. L is the likelihood ratio test statistic for model coefficients. Values of residual heterogeneity and L in black italics indicate statistical significance ($\alpha = 0.05$). Please see Figure A2 for mean effect sizes.

Figure S1. Frequency of earthworm ecological group richness across all studies and correlations among measures of introduced earthworm abundance in North American forests.



Meta-analytic mixed-effects model was used to evaluate the direction and strength of size effects representing the association between measures of introduced earthworm community abundance. Whisker bars are 95% confidence intervals. Effect sizes are Pearson's correlation coefficient and Fisher's r-to-z transformed coefficient was used for analysis. Earthworm biomass is biomass of non-native earthworms, earthworm density is number of introduced earthworms, and earthworm ecological group richness is the number of introduced earthworm ecological groups.

Figure S2. Effect sizes of relationships between introduced earthworm communities and total plant cover of forest understory communities in North America.



Meta-analytic mixed-effects models evaluated the direction and strength of size effects representing the association between a measure of introduced earthworm communities (density, biomass, earthworm ecological group richness) and total percent cover. Whisker bars are 95% confidence intervals. Effect sizes are Pearson's correlation coefficient and Fisher's r-to-z transformed coefficient was used for analysis. Earthworm biomass is biomass of introduced earthworms, earthworm density is number of introduced earthworms, and earthworm ecological group richness is the number of introduced earthworm ecological groups.