

Eisenhauer, N., Fisichelli, N. A., Frelich, L. E. and Reich, P. B. 2012. Interactive effects of global warming and ‘global worming’ on the initial establishment of native and exotic herbaceous plant species. – Oikos 121: 1121–1133.

## Appendix 1

Table A1. List of plant species used in the present experiment with plant functional group affiliation, origin and mean seed weight. *Aster macrophyllus* did not germinate in the present experiment.

Species	Plant functional group	Origin	Dry weight 1000 seeds (g)
<i>Aster macrophyllus</i>	forb	native	1.05
<i>Aquilegia canadensis</i>	forb	native	0.75
<i>Calamagrostis canadensis</i>	grass	native	0.10
<i>Lathyrus venosus</i>	legume	native	36.82
<i>Phleum pratense</i>	grass	exotic	0.45
<i>Plantago major</i>	forb	exotic	0.24
<i>Taraxacum officinale</i>	forb	exotic	0.57
<i>Trifolium pratense</i>	legume	exotic	1.33

Table A2. ANOVA table of F- and p-values for the effects of temperature (TE; ambient and +4°C), chamber (random effect nested within temperature), earthworms (EW; monoculture and three species mixture) and TE × EW on the survival and change of body fresh weight (both [% of initial]) of the earthworm species *Aporrectodea caliginosa* (ACA), *Lumbricus rubellus* (LRU) and *Lumbricus terrestris* (LTE). Random effects are given in italics.

Degrees of freedom	Temperature		Chamber(TE)		Earthworms		TE × EW	
	1,4		4,16		1,16		1,16	
	F	p	F	p	F	p	F	p
ACA survival	1.71	0.2606	<i>4.42</i>	<i>0.0135</i>	0.84	0.3724	0.84	0.3724
ACA weight	1.22	0.3319	<i>3.53</i>	<i>0.0301</i>	0.00	0.9742	0.18	0.6806
LRU survival	0.20	0.6779	<i>0.26</i>	<i>0.9015</i>	0.46	0.5066	0.46	0.5066
LRU weight	0.48	0.5274	<i>0.33</i>	<i>0.8562</i>	0.46	0.5073	0.00	0.9600
LTE survival	0.61	0.4789	<i>0.79</i>	<i>0.5475</i>	0.88	0.3625	1.15	0.2995
LTE weight	0.03	0.8665	<i>0.28</i>	<i>0.8885</i>	0.36	0.5584	1.25	0.2800

Table A3. ANOVA table of F- and p-values for the effects of temperature (TE; ambient and +4°C), chamber (random effect nested within temperature), earthworms (EW; control, *Aporrectodea caliginosa*, *Lumbricus rubellus*, *Lumbricus terrestris* and three species mixture) and TE × EW on soil water content, litter removal (day (D) 8, 15, 22, 29, 39), number (day 8, 15, 22, 29, 39), biomass, biomass per individual and species richness of total seedlings (day (D) 8, 15, 22, 29, 39), native seedlings and exotic seedlings, as well as on the ratio between the number, biomass and species richness of exotic and native species. Significant effects ( $p < 0.05$ ) are given in bold. Random effects are given in italics but not highlighted in bold.

Degrees of freedom	Temperature		Chamber(TE)		Earthworms		TE × EW	
	1,4		4,44		4,44		4,44	
	F	p	F	p	F	p	F	p
Soil water content (top)	<b>11.14</b>	<b>0.0289</b>	3.88	0.0087	<b>5.59</b>	<b>0.0010</b>	<b>2.65</b>	<b>0.0457</b>
Soil water content (bot)	0.34	0.5848	0.39	0.8157	0.59	0.6691	0.55	0.6986
Litter removal D8	0.42	0.5534	2.13	0.0928	<b>7.64</b>	<b>&lt;0.0001</b>	<b>2.84</b>	<b>0.0352</b>
Litter removal D15	0.22	0.6616	1.73	0.1610	<b>15.60</b>	<b>&lt;0.0001</b>	0.44	0.7806
Litter removal D22	0.00	0.9534	2.83	0.0356	<b>25.07</b>	<b>&lt;0.0001</b>	0.45	0.7728
Litter removal D29	1.13	0.3467	2.50	0.0556	<b>34.95</b>	<b>&lt;0.0001</b>	1.05	0.3912
Litter removal D36	0.37	0.5759	3.17	0.0224	<b>27.59</b>	<b>&lt;0.0001</b>	0.91	0.4659
Total seedlings D8	2.21	0.2112	3.29	0.0189	<b>2.64</b>	<b>0.0460</b>	1.38	0.2575
Total seedlings D15	2.14	0.2176	2.05	0.1027	<b>11.82</b>	<b>&lt;0.0001</b>	1.41	0.2471
Total seedlings D22	0.17	0.6991	3.29	0.0189	<b>17.48</b>	<b>&lt;0.0001</b>	<b>2.61</b>	<b>0.0476</b>
Total seedlings D29	0.00	0.9724	3.37	0.0169	<b>16.54</b>	<b>&lt;0.0001</b>	1.74	0.1584
Total seedlings D36	0.00	0.9799	5.73	0.0008	<b>22.09</b>	<b>&lt;0.0001</b>	0.96	0.4408
Native seedling number	<b>13.84</b>	<b>0.0203</b>	0.46	0.7663	1.18	0.3316	1.39	0.2523
Exotic seedling number	0.36	0.5813	5.32	0.0014	<b>20.27</b>	<b>&lt;0.0001</b>	1.88	0.1307
Total seedling biomass	2.67	0.1775	2.32	0.0713	<b>6.56</b>	<b>0.0003</b>	1.58	0.1950
Native biomass	4.49	0.1011	0.42	0.7923	0.60	0.6677	1.36	0.2638
Exotic biomass	2.57	0.1840	2.04	0.1048	<b>7.30</b>	<b>0.0001</b>	1.88	0.1310
Seedling species richness D8	1.09	0.3549	2.29	0.0744	2.25	0.0781	1.60	0.1911
Seedling species richness D15	5.42	0.0802	0.93	0.4559	0.16	0.9557	0.36	0.8323
Seedling species richness D22	0.05	0.8315	1.41	0.2454	2.17	0.0881	0.75	0.5626
Seedling species richness D29	2.74	0.1732	0.78	0.5438	<b>3.20</b>	<b>0.0213</b>	0.84	0.5045
Seedling species richness D36	0.42	0.5517	4.30	0.0049	<b>6.19</b>	<b>0.0005</b>	1.84	0.1369
Native species richness	0.86	0.4058	0.56	0.6959	<b>3.75</b>	<b>0.0102</b>	2.09	0.0975
Exotic species richness	0.06	0.8214	4.55	0.0036	<b>4.94</b>	<b>0.0022</b>	0.89	0.4751
Biomass / seedling	2.94	0.1615	0.94	0.4484	<b>9.96</b>	<b>&lt;0.0001</b>	0.53	0.7154
Native bm / seedling	0.14	0.7248	0.96	0.4404	0.77	0.5521	1.00	0.4226
Exotic bm / seedling	5.78	0.0736	0.50	0.7330	<b>10.60</b>	<b>&lt;0.0001</b>	0.39	0.8124
Exotics / natives number	6.39	0.0645	0.63	0.6431	0.48	0.7520	<b>3.65</b>	<b>0.0117</b>
Exotics / natives species richness	0.12	0.7458	0.92	0.4598	1.85	0.1361	<b>2.62</b>	<b>0.0472</b>
Exotics / natives biomass	0.58	0.4869	1.29	0.2940	1.29	0.2913	1.25	0.3069

Table A4. MANOVA table of F- and p-values for within (Roy's greatest root) and between subject effects of time (8, 15, 22, 29 and 36 days), temperature (TE; ambient and +4°C), chamber (random effect nested within temperature), earthworms (EW; control, *Aporrectodea caliginosa*, *Lumbricus rubellus*, *Lumbricus terrestris* and three species mixture) and interactions on litter removal, number and species richness of seedlings. Significant effects ( $p < 0.05$ ) are given in bold. Random effects are given in italics but not highlighted in bold.

	DF	Litter removal		Seedling number		Seedling species richness	
		F	p	F	p	F	p
<u>Within-subject effects</u>							
Time	4,42	43.96	<0.0001	<b>85.93</b>	<b>&lt;0.0001</b>	<b>69.36</b>	<b>&lt;0.0001</b>
Time × Temperature	4,42	<b>3.51</b>	<b>0.0147</b>	1.29	0.2902	0.68	0.6128
Time × Chamber	4,45	<i>1.87</i>	<i>0.1329</i>	<i>2.96</i>	<i>0.0295</i>	<i>6.06</i>	<i>0.0005</i>
Time × Earthworm	4,45	<b>26.21</b>	<b>&lt;0.0001</b>	<b>15.01</b>	<b>&lt;0.0001</b>	<b>7.69</b>	<b>&lt;0.0001</b>
Time × TE × EW	4,45	<b>3.32</b>	<b>0.0181</b>	<b>2.97</b>	<b>0.0292</b>	<b>4.06</b>	<b>0.0068</b>
<u>Between-subject effects</u>							
Temperature	1,45	0.35	0.5586	1.49	0.2281	3.82	0.0570
Chamber	4,45	<i>2.94</i>	<i>0.0307</i>	<i>4.82</i>	<i>0.0025</i>	<i>2.27</i>	<i>0.0663</i>
Earthworm	4,45	<b>27.21</b>	<b>&lt;0.0001</b>	19.18	<0.0001	<b>4.88</b>	<b>0.0024</b>
Temperature × Earthworm	4,45	0.94	0.4488	1.84	0.1383	0.49	0.7461

Table A5. Results of structural equation models of earthworm and warming effects on (a) seedling number, (b) seedling biomass, and (c) seedling species richness of exotic and native plant species illustrated in Fig. 5 and Fig. A3. Given are the unstandardized path coefficients (estimates), standard error of regression weight (SE), the critical value for regression weight (CR;  $z = \text{estimate} / \text{SE}$ ) and level of significance for regression weight (p). For more information of exogenous and endogenous variables as well as on model fit see main text. Significant relationships ( $p < 0.05$ ) are given in bold. \*\*\* =  $p < 0.001$ .

Variables	Variables	Estimate	SE	CR	p
(a) Seedling number					
<b>Litter biomass</b>	← <i>Lumbricus rubellus</i>	<b>-0.469</b>	<b>0.15</b>	<b>-3.181</b>	<b>0.001</b>
<b>Soil water content</b>	← <b>Warming</b>	<b>-0.029</b>	<b>0.01</b>	<b>-5.455</b>	<b>***</b>
<b>Soil water content</b>	← <i>Lumbricus terrestris</i>	<b>-0.084</b>	<b>0.02</b>	<b>-3.845</b>	<b>***</b>
<b>Litter biomass</b>	← <i>Lumbricus terrestris</i>	<b>-1.101</b>	<b>0.15</b>	<b>-7.416</b>	<b>***</b>
<b>Number exotics</b>	← <b>Soil water content</b>	<b>16.581</b>	<b>5.7</b>	<b>2.908</b>	<b>0.004</b>
Number natives	← Warming	0.198	0.14	1.472	0.141
<b>Number natives</b>	← <b>Litter biomass</b>	<b>0.665</b>	<b>0.29</b>	<b>2.278</b>	<b>0.023</b>
<b>Number exotics</b>	← <i>Lumbricus terrestris</i>	<b>-9.778</b>	<b>1.71</b>	<b>-5.726</b>	<b>***</b>
<b>Number exotics</b>	← <i>Lumbricus rubellus</i>	<b>-4.2</b>	<b>1.26</b>	<b>-3.325</b>	<b>***</b>
<b>Number exotics</b>	← <b>Litter biomass</b>	<b>-2.286</b>	<b>1.04</b>	<b>-2.202</b>	<b>0.028</b>
Number natives	← Soil water content	-3.734	2.56	-1.457	0.145
(b) Seedling biomass					
<b>Litter biomass</b>	← <i>Lumbricus rubellus</i>	<b>-0.469</b>	<b>0.15</b>	<b>-3.181</b>	<b>0.001</b>
<b>Soil water content</b>	← <b>Warming</b>	<b>-0.029</b>	<b>0.01</b>	<b>-5.455</b>	<b>***</b>
<b>Soil water content</b>	← <i>Lumbricus terrestris</i>	<b>-0.084</b>	<b>0.02</b>	<b>-3.845</b>	<b>***</b>
<b>Litter biomass</b>	← <i>Lumbricus terrestris</i>	<b>-1.101</b>	<b>0.15</b>	<b>-7.416</b>	<b>***</b>
<b>Biomass exotics</b>	← <b>Soil water content</b>	<b>0.98</b>	<b>0.27</b>	<b>3.607</b>	<b>***</b>
Biomass exotics	← <i>Lumbricus terrestris</i>	-0.082	0.07	-1.208	0.227
<b>Biomass exotics</b>	← <i>Lumbricus rubellus</i>	<b>0.238</b>	<b>0.05</b>	<b>4.865</b>	<b>***</b>
<b>Biomass exotics</b>	← <b>Litter biomass</b>	<b>-0.082</b>	<b>0.04</b>	<b>-2.043</b>	<b>0.041</b>
<b>Biomass exotics</b>	← <i>Aporrectodea caliginosa</i>	<b>0.092</b>	<b>0.05</b>	<b>2.002</b>	<b>0.045</b>
Biomass natives	← <i>Aporrectodea caliginosa</i>	0.006	0.01	0.904	0.366
Biomass natives	← Warming	0.002	0.00	1.405	0.160
<b>Biomass exotics</b>	← <b>Warming</b>	<b>0.057</b>	<b>0.01</b>	<b>4.123</b>	<b>***</b>
e2	↔ e3	0.001	0.00	1.454	0.146

(c) Species richness

<b>Litter biomass</b>	← <i>Lumbricus rubellus</i>	<b>-0.469</b>	<b>0.15</b>	<b>-3.181</b>	<b>0.001</b>
<b>Soil water content</b>	← <b>Warming</b>	<b>-0.029</b>	<b>0.01</b>	<b>-5.455</b>	<b>***</b>
<b>Soil water content</b>	← <i>Lumbricus terrestris</i>	<b>-0.084</b>	<b>0.02</b>	<b>-3.845</b>	<b>***</b>
<b>Litter biomass</b>	← <i>Lumbricus terrestris</i>	<b>-1.101</b>	<b>0.15</b>	<b>-7.416</b>	<b>***</b>
<b>Richness exotics</b>	← <b>Soil water content</b>	<b>2.357</b>	<b>0.78</b>	<b>3.024</b>	<b>0.002</b>
<b>Richness exotics</b>	← <i>Lumbricus terrestris</i>	<b>-0.488</b>	<b>0.19</b>	<b>-2.524</b>	<b>0.012</b>
<b>Richness exotics</b>	← <b>Litter biomass</b>	<b>-0.231</b>	<b>0.12</b>	<b>-2.015</b>	<b>0.044</b>
<b>Richness natives</b>	← <b>Soil water content</b>	<b>-1.702</b>	<b>1.06</b>	<b>-1.606</b>	<b>0.108</b>
<b>Richness exotics</b>	← <b>Warming</b>	<b>0.081</b>	<b>0.04</b>	<b>2.095</b>	<b>0.036</b>
<b>Richness exotics</b>	← <i>Lumbricus rubellus</i>	<b>-0.34</b>	<b>0.14</b>	<b>-2.415</b>	<b>0.016</b>
<b>Richness natives</b>	← <i>Lumbricus terrestris</i>	<b>-0.758</b>	<b>0.24</b>	<b>-3.212</b>	<b>0.001</b>
<b>Richness natives</b>	← <i>Lumbricus rubellus</i>	<b>-0.497</b>	<b>0.22</b>	<b>-2.292</b>	<b>0.022</b>
e2	↔ e3	0.058	0.05	1.118	0.264

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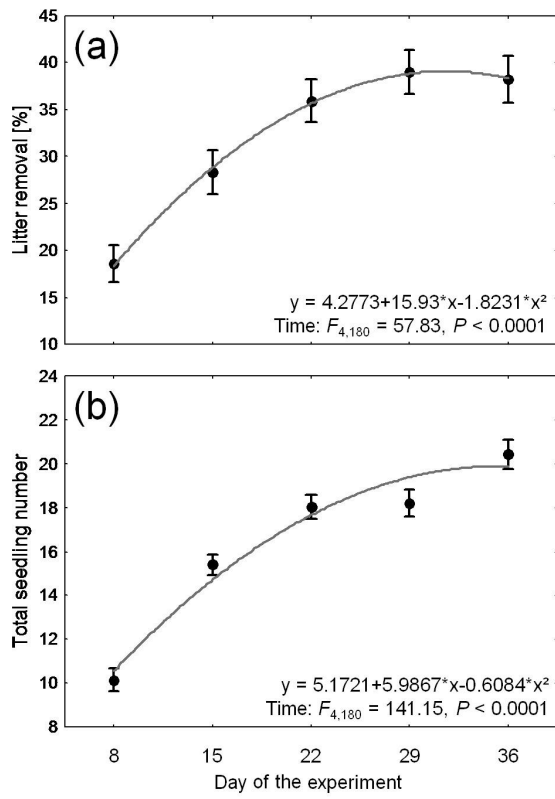


Figure A1. Time course of (a) litter removal and (b) number of seedlings indicating a saturation of both processes towards the end of the experiment. Higher numbers of seedlings at day 36 compared to day 29 were due to a more detailed assessment of seedling numbers during harvest.

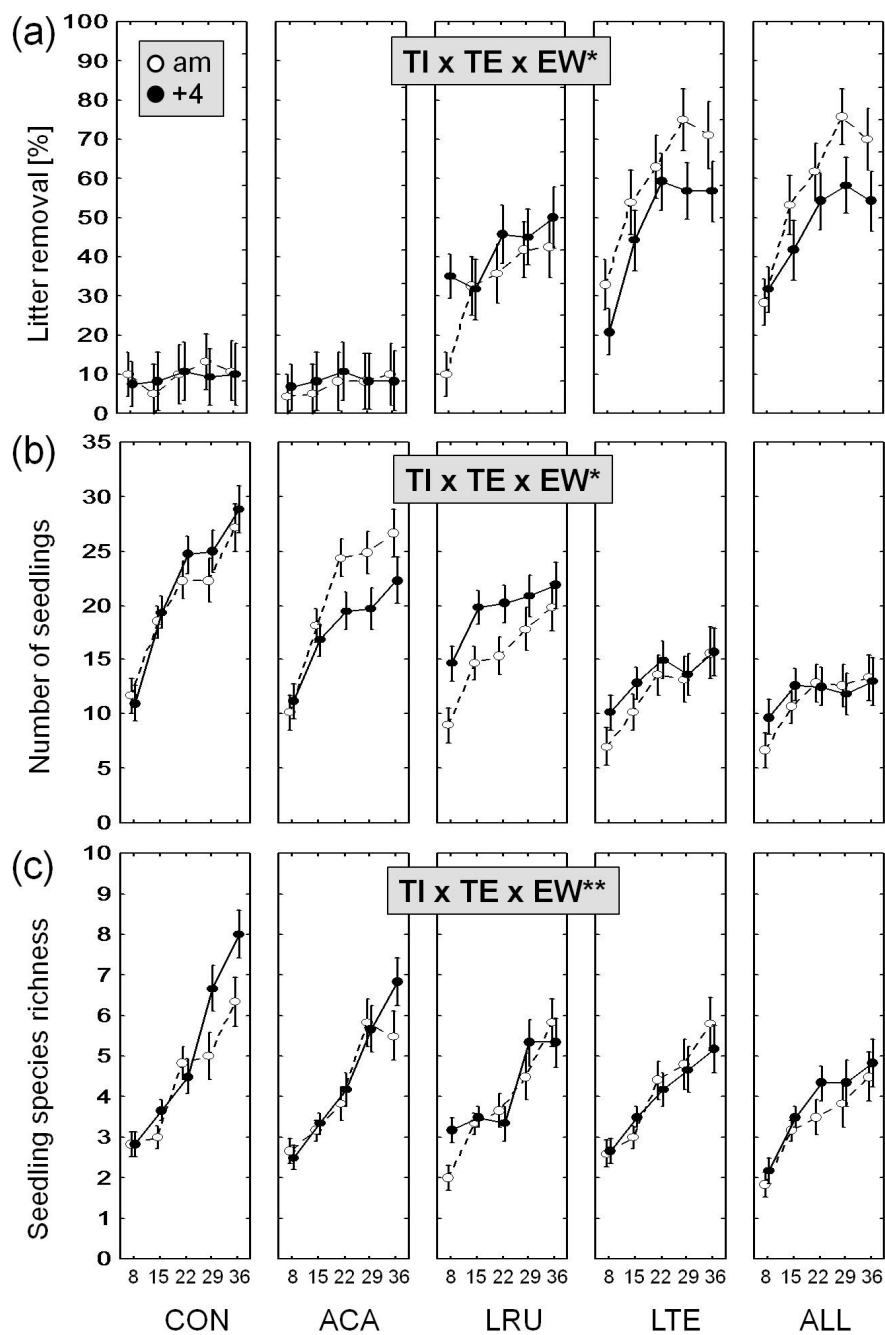


Figure A2. Litter removal (a), number (b), and species richness (c) of seedlings as affected by time (TI; 8, 15, 22, 29, 36 days after start of the experiment), temperature (TE; grey circles = ambient, black circles = +4°C) and earthworms (EW; CON = control without earthworms, ACA = *Aporrectodea caliginosa* (endogeic), LRU = *Lumbricus rubellus* (epi-endogeic), LTE = *Lumbricus terrestris* (anecic), ALL = combination of all three earthworm species). Means with standard error and standard deviation. \* = p < 0.05, \*\* = p < 0.01 (Table A4).

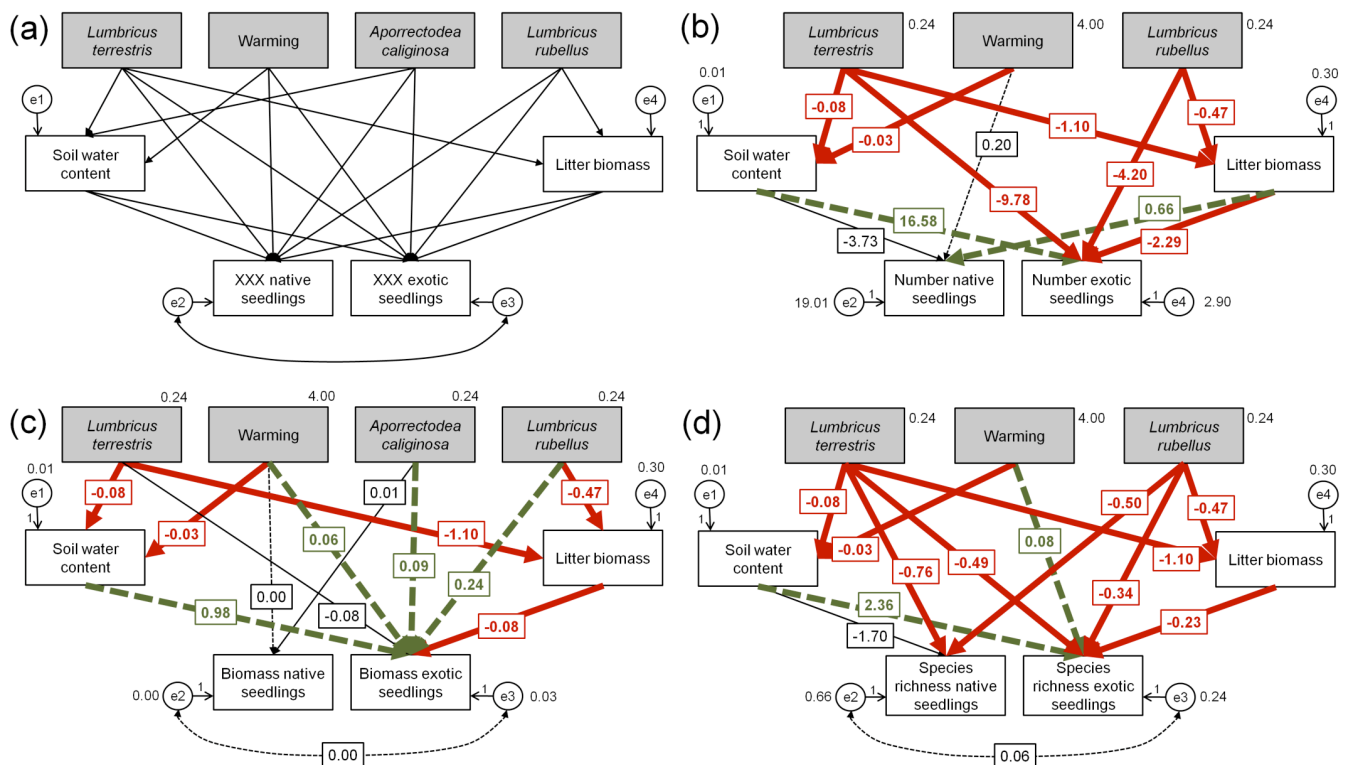


Figure A3. Structural equation models (SEM). (a) Initial model showing all tested causal influences of presence of different earthworm species and warming (exogenous variables; grey rectangles) on soil water content, litter biomass and performance (number, biomass or species richness) of exotic and native seedlings (endogenous variables; white rectangles). SEM of (b) seedling number, (c) seedling biomass and (d) seedling species richness. Numbers on arrows are unstandardized path coefficients. Width of the arrows indicated the strength of the causal influence: bold arrows indicate significant unstandardized path coefficients ( $P < 0.05$ ), fine arrows indicate non-significant path coefficients ( $P > 0.05$ ), double-headed arrows indicate correlations between error terms. Black arrows indicate non-significant relationships, green dashed arrows significant positive relationships and red solid arrows significant negative relationships. Circles indicate error terms (e1-e4). For more information see main text, Supplementary material Appendix Table A5 and Fig. 5.