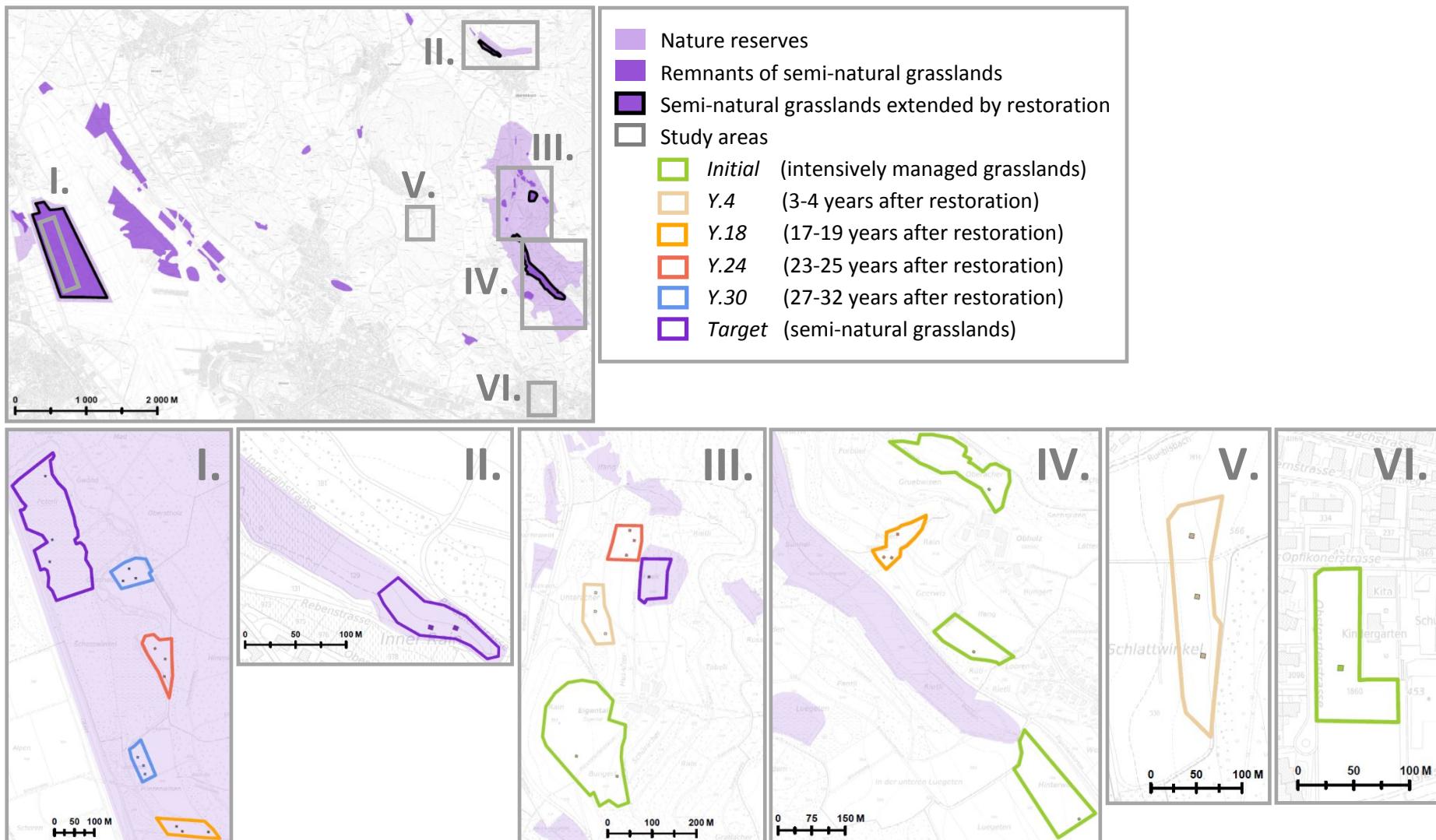


Supplementary material to

**Resch et al: Long-term recovery of above-and belowground interactions in restored grasslands after topsoil removal and seed addition. Journal of Applied Ecology**

**Figure S1:** Detailed description of the study area. The overview map on top shows the two larger nature reserves *Altläufe der Glatt* (left; I.) and *Eigental* (right; III. & IV.), as well as the isolated remnants of the surrounding, legally protected semi-natural grasslands in 1980. Patches of targeted semi-natural grasslands chosen to be improved in quality, extended and re-connected are indicated by black borders. Single clusters of study areas (I. – VI.) are magnified to show the nested arrangement of the sites in the field. Filled, colored squares within sites represent 5 m x 5 m plots sampled for the aboveground plant community.



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**Figure S2:** Photos of the intensively managed (*Initial*), restored (Y.4-30) and semi-natural (*Target*) grassland ecosystems. For each grassland ecosystem overview photos are shown for selected plots (top rows) and their respective species community (bottom rows). Colour codes follow Figure S1.

**(a) Degraded ecosystem (*Initial*)**



**(b) Restored ecosystem (Y.4)**



**(c) Restored ecosystem (Y.18)**



**(d) Restored ecosystem (Y.24)**



**(e) Restored ecosystem (Y.30)**



**(f) Semi-natural ecosystem (*Target*)**



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**Table S1:** Description of the 36 initial, restored and target plots. Treatment: *Initial* = intensively managed grasslands; Restored = restored grasslands after topsoil removal plus seed addition of target plant species from nearby semi-natural grasslands; *Target* = semi-natural grasslands. Year: Year when restoration took place. Age class: Plots grouped into age classes depending on years since restoration. X and Y coordinates are given in meters.

Management: Frequency and intensity of mowing and manuring in one year (only in *Initial*). In recently restored grasslands (age class *Y.4*), mowing started earliest 5 years after restoration, but depended on the local aboveground plant biomass production. Tillage: Last time the site was tilled. Land-use: Current agricultural use for *Initial* sites; agricultural use before restoration for all restored and *Target* sites; TG = temporary grassland (resown every sixth year); PG = permanent grassland. Mowing: Earliest date of biomass harvest. Exact yearly dates depended on local and seasonal weather conditions. Soil type: Soil types based on soil mapping survey 1991 or 1993. Soil texture: determined by the sediment method (Gee & Bauder, 1986) and classified into soil textural classes according to FAO (1990). Slope: Slope gradient in percent according to classes defined by FAO (1990).

Plot	Treatment	Year	Age class	X Coordinate	Y Coordinate	Management	Tillage	Land use	Mowing	Soil type	Soil texture	Slope
1	<i>Initial</i>			689 080.243	258 246.682	4-5 times	≤ 10 years	TG	~ May 1	calcaric Cambisol	loam	2-5
2	<i>Initial</i>			689 171.878	258 201.273	2-3 times	> 50 years	PG	~ May 1	calcaric Cambisol	clay	5-10
3	<i>Initial</i>			689 655.412	257 775.139	2-3 times	> 50 years	PG	~ May 1	calcaric Cambisol	clay loam	10-15
4	<i>Initial</i>			689 621.276	257 411.625	2-3 times	> 50 years	PG	~ May 1	Cambisol	loam	5-10
5	<i>Initial</i>			689 856.414	257 037.378	4-5 times	≤ 10 years	TG	~ May 1	Cambisol	loam	2-5
6	<i>Initial</i>			689 182.964	255 311.208	4-5 times	≤ 10 years	TG	~ May 1	calcaric Cambisol	loam	1-2
7	Restored	2015	<i>Y.4</i>	689 123.809	258 614.692	none	> 50 years	PG		calcaric Cambisol	clay	2-5
8	Restored	2015	<i>Y.4</i>	689 122.941	258 572.666	none	> 50 years	PG		calcaric Cambisol	clay	2-5
9	Restored	2015	<i>Y.4</i>	689 145.467	258 522.445	none	> 50 years	PG		calcaric Cambisol	clay	2-5
10	Restored	2014	<i>Y.4</i>	687 737.944	258 467.715	none	≤ 10 years	TG		calcaric Cambisol	loam	2-5
11	Restored	2014	<i>Y.4</i>	687 744.093	258 400.707	none	≤ 10 years	TG		calcaric Cambisol	clay loam	2-5
12	Restored	2014	<i>Y.4</i>	687 750.405	258 335.423	none	≤ 10 years	TG		calcaric Cambisol	loam	2-5
13	Restored	2001	<i>Y.18</i>	689 451.593	257 674.796	twice	> 50 years	PG	June 15 + Sept 1	calcaric Cambisol	clay loam	15-30
14	Restored	2001	<i>Y.18</i>	689 438.375	257 622.179	twice	> 50 years	PG	June 15 + Sept 1	calcaric Cambisol	clay loam	5-10
15	Restored	2001	<i>Y.18</i>	689 420.595	257 623.110	twice	> 50 years	PG	June 15 + Sept 1	calcaric Cambisol	clay loam	2-5
16	Restored	1999	<i>Y.18</i>	682 697.703	257 257.153	once	> 50 years	PG	Sept 1	Gleysol	clay loam	1-2
17	Restored	1999	<i>Y.18</i>	682 712.441	257 244.638	once	> 25 years	TG	Sept 1	Gleysol	clay	1-2
18	Restored	1999	<i>Y.18</i>	682 777.403	257 243.002	once	> 25 years	TG	Sept 1	Gleysol	silt clay loam	1-2
19	Restored	1995	<i>Y.24</i>	689 200.522	258 754.892	once	> 50 years	PG	Oct 1	calcaric Cambisol	clay loam	15-30
20	Restored	1995	<i>Y.24</i>	689 210.517	258 731.950	once	> 50 years	PG	Oct 1	calcaric Cambisol	clay	15-30
21	Restored	1995	<i>Y.24</i>	689 193.025	258 698.993	once	> 50 years	PG	Oct 1	calcaric Cambisol	clay	15-30
22	Restored	1993	<i>Y.24</i>	682 643.793	257 704.006	once	> 25 years	TG	Sept 1	gleytic Cambisol	clay loam	1-2
23	Restored	1993	<i>Y.24</i>	682 669.373	257 677.950	once	> 25 years	TG	Sept 1	gleytic Cambisol	clay loam	1-2

24	Restored	1993 Y.24	682 667.347	257 634.180	once	> 25 years	TG	Sept 1	gleyc Cambisol	clay loam	1-2
25	Restored	1991 Y.30	682 600.547	257 431.082	once	> 25 years	PG	Sept 1	Gleysol	clay loam	1-2
26	Restored	1991 Y.30	682 614.871	257 410.344	once	> 25 years	PG	Sept 1	Gleysol	clay loam	1-2
27	Restored	1991 Y.30	682 618.829	257 388.881	once	> 25 years	PG	Sept 1	Gleysol	clay loam	1-2
28	Restored	1986 Y.30	682 579.189	257 905.185	once	> 50 years	PG	Sept 1	Gleysol	clay loam	1-2
29	Restored	1986 Y.30	682 595.657	257 881.097	once	> 50 years	PG	Sept 1	Gleysol	clay	1-2
30	Restored	1986 Y.30	682 563.949	257 874.324	once	> 50 years	PG	Sept 1	Gleysol	silt clay	1-2
31	<i>Target</i>		689 243.905	258 650.264	once	> 50 years	PG	Oct 1	calcaric Cambisol	clay	15-30
32	<i>Target</i>		688 745.706	260 651.789	once	> 50 years	PG	July 1	calcaric Cambisol	clay loam	30-60
33	<i>Target</i>		688 770.481	260 651.169	once	> 50 years	PG	July 1	calcaric Cambisol	clay loam	30-60
34	<i>Target</i>		682 380.151	257 922.449	once	> 50 years	PG	Sept 1	Gleysol	clay	1-2
35	<i>Target</i>		682 369.291	258 137.826	once	> 50 years	PG	Sept 1	gleyc Cambisol	silty clay	1-2
36	<i>Target</i>		682 386.682	257 977.765	once	> 50 years	PG	Sept 1	Gleysol	loam	2-5

## References

- FAO. 1990. Guidelines for soil description, third ed. Land and Water Development Division at the Food and Agriculture Organization of the United Nations (FAO), Rome.
- Gee, G.W., & Bauder, J.W. (1986). Particle-size analysis 1. Methods of soil analysis: Part 1—Physical and mineralogical methods (383-411).

Supplementary material to

**Resch et al: Long-term recovery of above-and belowground interactions in restored grasslands after topsoil removal and seed addition. Journal of Applied Ecology**

**Table S2:** List of potential target plant species placed on the restored sites via fresh, seed-containing hay transfer or hand-collected seed application.

Species	Species	Species
<i>Achillea millefolium</i> L. s.l.	<i>Dianthus carthusianorum</i> L.	<i>Plantago lanceolata</i> L.
<i>Agrimonia eupatoria</i> L.	<i>Digitalis grandiflora</i> Mill.	<i>Plantago media</i> L.
<i>Agrimonia procera</i> Wallr.	<i>Echium vulgare</i> L.	<i>Platanthera bifolia</i> (L.) Rich.
<i>Agrostis canina</i> L.	<i>Epipactis palustris</i> (L.) Crantz	<i>Poa pratensis</i> L.
<i>Agrostis capillaris</i> L.	<i>Equisetum arvense</i> L.	<i>Polygala amarella</i> Crantz
<i>Agrostis gigantea</i> Roth	<i>Equisetum palustre</i> L.	<i>Polygala chamaebuxus</i> L.
<i>Agrostis stolonifera</i> L.	<i>Eupatorium cannabinum</i> L.	<i>Polygala comosa</i> Schkuhr
<i>Ajuga reptans</i> L.	<i>Euphorbia cyparissias</i> L.	<i>Polygala vulgaris</i> L.
<i>Allium oleraceum</i> L.	<i>Euphrasia rostkoviana</i> Hayne s.str.	<i>Populus tremula</i> L.
<i>Allium vineale</i> L.	<i>Festuca arundinacea</i> Schreb. s.l.	<i>Potentilla erecta</i> (L.) Raeusch.
<i>Anacamptis pyramidalis</i> (L.) Rich.	<i>Festuca ovina</i> agg	<i>Potentilla sterilis</i> (L.) Garcke
<i>Anemone nemorosa</i> L.	<i>Festuca pratensis</i> Huds. s.l.	<i>Primula elatior</i> (L.) L. s.str.
<i>Angelica sylvestris</i> L.	<i>Festuca rubra</i> L. s.l.	<i>Primula veris</i> L. s.str.
<i>Anthericum ramosum</i> L.	<i>Filipendula ulmaria</i> (L.) Maxim.	<i>Prunella grandiflora</i> (L.) Scholler
<i>Anthoxanthum odoratum</i> L.	<i>Fragaria vesca</i> L.	<i>Prunella vulgaris</i> L.
<i>Anthyllis vulneraria</i> L. s.str.	<i>Frangula alnus</i> Mill.	<i>Prunus spinosa</i> L.
<i>Anthyllis vulneraria</i> subsp. <i>carpatica</i> (Pant.) Nyman	<i>Fraxinus excelsior</i> L.	<i>Quercus petraea</i> Liebl.
<i>Arrhenatherum elatius</i> (L.) J. & C. Presl	<i>Galium album</i> Mill.	<i>Quercus robur</i> L.
<i>Artemesia absinthium</i> L.	<i>Galium mollugo</i> L.	<i>Ranunculus acris</i> L. s.str.
<i>Asperula cynanchica</i> L.	<i>Galium palustre</i> L.	<i>Ranunculus acris</i> subsp. <i>friesianus</i> (Jord.) Syme
<i>Aster amellus</i> L.	<i>Galium pumilum</i> Murray	<i>Ranunculus bulbosus</i> L.
<i>Betula pendula</i> Roth	<i>Galium uliginosum</i> L.	<i>Ranunculus tuberosus</i> Lapeyr.
<i>Betula pubescens</i> Ehrh.	<i>Galium verum</i> L. s.str.	<i>Rhamnus cathartica</i> L.
<i>Blackstonia perfoliata</i> (L.) Huds.	<i>Genista tinctoria</i> L.	<i>Rhinanthus alectorolophus</i> (Scop.) Pollich
<i>Brachypodium pinnatum</i> (L.) P. Beauv.	<i>Gentiana germanica</i> Willd.	<i>Rhinanthus minor</i> L.
<i>Briza media</i> L.	<i>Glechoma hederacea</i> L.	<i>Rosa canina</i> L. cf
<i>Bromus erectus</i> Huds. s.str.	<i>Gymnadenia conopsea</i> (L.) R. Br.	<i>Rubus caesius</i> L.
<i>Buphtalmum salicifolium</i> L.	<i>Gymnadenia odoratissima</i> (L.) Rich.	<i>Rumex acetosa</i> L.
<i>Calamagrostis epigejos</i> (L.) Roth	<i>Helianthemum nummularium</i> (L.) Mill.	<i>Salvia pratensis</i> L.
<i>Calluna vulgaris</i> (L.) Hull	<i>Helictotrichon pubescens</i> (Huds.) Pilg.	<i>Sanguisorba minor</i> Scop. s.str.
<i>Calystegia sepium</i> (L.) R. Br.	<i>Hieracium murorum</i> aggr.	<i>Sanguisorba officinalis</i> L.
<i>Campanula patula</i> L.	<i>Hieracium umbellatum</i> aggr.	<i>Scabiosa columbaria</i> L. s.str.
<i>Campanula persicifolia</i> L.	<i>Hippocratea comosa</i> L.	<i>Selinum carvifolia</i> (L.) L.
<i>Campanula rapunculus</i> L.	<i>Holcus lanatus</i> L.	<i>Serratula tinctoria</i> L. s.str.
<i>Carex acuta</i> aggr.	<i>Hypericum maculatum</i> Crantz s.str.	<i>Silaum silaus</i> (L.) Schinz & Thell.
<i>Carex acutiformis</i> Ehrh.	<i>Hypericum perforatum</i> L. s.str.	<i>Silene flos-cuculi</i> (L.) Clairv.
<i>Carex caryophyllea</i> Latourr.	<i>Inula helvetica</i> Weber	<i>Sorbus aria</i> (L.) Crantz
<i>Carex flacca</i> Schreb.	<i>Inula salicina</i> L.	<i>Stachys officinalis</i> (L.) Trevis. s.l.
<i>Carex hartmanii</i> Cajander	<i>Iris sibirica</i> L.	<i>Stachys palustris</i> L.
<i>Carex hirta</i> L.	<i>Juncus conglomeratus</i> L.	<i>Stachys recta</i> L.
<i>Carex hostiana</i> DC.	<i>Juncus effusus</i> L.	<i>Stellaria graminea</i> L.

<i>Carex montana</i> L.	<i>Juncus inflexus</i> L.	<i>Stellaria media</i> (L.) Vill.
<i>Carex pallescens</i> L.	<i>Knautia arvensis</i> (L.) Coul.	<i>Succisa pratensis</i> Moench
<i>Carex panicea</i> L.	<i>Koeleria pyramidata</i> (Lam.) P. Beauv.	<i>Symphytum officinale</i> aggr.
<i>Carex pulicaris</i> L.	<i>Lathyrus pratensis</i> L.	<i>Taraxacum officinale</i> aggr.
<i>Carex sylvatica</i> Huds.	<i>Leucanthemum vulgare</i> Lam.	<i>Thymus pulegioides</i> L. s.str.
<i>Carex tomentosa</i> L.	<i>Leontodon hispidus</i> L.	<i>Tofieldia calyculata</i> (L.) Wahlenb.
<i>Carlina vulgaris</i> L.	<i>Linum catharticum</i> L.	<i>Tragopogon dubius</i> Scop.
<i>Carpinus betulus</i> L.	<i>Lolium perenne</i> L.	<i>Tragopogon pratensis</i> L.
<i>Centaurea jacea</i> L. s.str.	<i>Lotus corniculatus</i> L. s.l.	<i>Tragopogon pratensis</i> subsp. <i>orientalis</i> (L.) Čelak.
<i>Centaurea jacea</i> subsp. <i>angustifolia</i> Greml.	<i>Lotus pedunculatus</i> Cav.	<i>Trifolium campestre</i> Schreb.
<i>Centaurea scabiosa</i> L.	<i>Luzula campestris</i> (L.) DC.	<i>Trifolium dubium</i> Sibth.
<i>Centaurium erythraea</i> Rafn	<i>Luzula multiflora</i> aggr.	<i>Trifolium medium</i> L.
<i>Cerastium fontanum</i> subsp. <i>vulgare</i> (Hartm.) Greuter	<i>Lysimachia vulgaris</i> L.	<i>Trifolium montanum</i> L.
<i>Cirsium arvense</i> (L.) Scop.	<i>Lythrum salicaria</i> L.	<i>Trifolium ochroleucon</i> Huds.
<i>Cirsium oleraceum</i> (L.) Scop.	<i>Medicago lupulina</i> L.	<i>Trifolium pratense</i> L. s.str.
<i>Cirsium palustre</i> (L.) Scop.	<i>Melampyrum arvense</i> L.	<i>Trifolium repens</i> L. s.l.
<i>Clinopodium vulgare</i> L.	<i>Melittis melissophyllum</i> L.	<i>Trisetum flavescens</i> (L.) P. Beauv.
<i>Colchicum autumnale</i> L.	<i>Molinia caerulea</i> (L.) Moench	<i>Valeriana dioica</i> L.
<i>Cornus sanguinea</i> L.	<i>Onobrychis viciifolia</i> Scop.	<i>Valeriana officinalis</i> L.
<i>Crataegus monogyna</i> aggr.	<i>Ononis repens</i> L.	<i>Veronica chamaedrys</i> L.
<i>Crepis biennis</i> L.	<i>Ophrys apifera</i> Huds.	<i>Viburnum opulus</i> L.
<i>Cynosurus cristatus</i> L.	<i>Ophrys insectifera</i> L.	<i>Vicia cracca</i> L. s.str.
<i>Dactylis glomerata</i> L.	<i>Orchis ustulata</i> L. cf	<i>Viola hirta</i> L.
<i>Dactylorhiza incarnata</i> (L.) Soó s.str.	<i>Orchis ustulata</i> L. cf	
<i>Dactylorhiza maculata</i> (L.) Soó	<i>Origanum vulgare</i> L.	
<i>Dactylorhiza majalis</i> (Rchb.) P. F. Hunt & Summerh.	<i>Peucedanum cervaria</i> (L.) Lapeyr.	
<i>Danthonia decumbens</i> (L.) DC.	<i>Phleum pratense</i> L.	
<i>Daucus carota</i> L.	<i>Picea abies</i> (L.) H. Karst.	
<i>Deschampsia cespitosa</i> (L.) P. Beauv.	<i>Pimpinella saxifraga</i> L.	
<i>Dianthus armeria</i> L.	<i>Pimpinella saxifraga</i> L.	

Supplementary material to

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**Table S3:** Results from generalized linear mixed effects models (GLMM) for the effect of time since restoration on belowground abiotic properties. All models included a random intercept for clusters and sites (Fig. S1). df = degrees of freedom;  $\chi^2$  = Chi-squared; P = significance level ( $\alpha \leq 0.05$ , bold); *Initial* = intensively managed grasslands; Y.4-30 = restored grasslands; *Target* = semi-natural grasslands; Total N pool = total nitrogen pool ( $t \text{ ha}^{-1} 12\text{cm}^{-1}$ ); Organic C pool = organic carbon pool ( $t \text{ ha}^{-1} 12\text{cm}^{-1}$ ); pH = soil pH ( $\text{CaCl}_2$ ); Bulk density ( $\text{g cm}^{-3}$ ); Field capacity (%). Different lower-case letters indicate significant differences between different aged restoration, initial and target plots.

Variable	Overall			Pairwise comparison					
	df	$\chi^2$	P	<i>Initial</i>	Y.4	Y.18	Y.24	Y.30	<i>Target</i>
Total N pool	5,30	23.486	<0.001	3.67 ± 0.47ab	1.47 ± 0.29 c	2.33 ± 0.29bc	2.85 ± 0.37 abc	4.08 ± 0.33 a	4.07 ± 0.24 a
Organic C pool	5,30	55.076	<0.001	34.27 ± 4.44 bc	13.22 ± 2.46 d	26.57 ± 4.18 c	31.93 ± 3.94 bc	41.21 ± 3.18 ab	49.45 ± 3.82 a
pH	5,30	14.966	0.011	5.62 ± 0.22 b	6.22 ± 0.35 a	6.87 ± 0.16 a	6.26 ± 0.28 a	6.95 ± 0.31 ab	6.77 ± 0.17 a
Bulk density	5,30	7.517	0.185	1.09 ± 0.03 a	1.17 ± 0.06 a	1.00 ± 0.08 a	1.01 ± 0.06 a	0.72 ± 0.06 a	0.95 ± 0.10 a
Field capacity	5,30	12.523	0.028	24.35 ± 1.24ab	21.22 ± 2.00 b	28.20 ± 2.97ab	27.74 ± 1.83 ab	39.51 ± 2.30 a	31.84 ± 2.57ab

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**Table S4:** Permutation based p-values (n = 999) indicating whether ecosystem coupling was significantly greater than the randomly generated null model. Values are provided for all, biotic-biotic, abiotic-biotic, and abiotic-abiotic interactions. Values in bold represent p-values < 0.05. *Initial* = intensively managed grasslands; *Y.4-30* = restored grasslands; *Target* = semi-natural grasslands.

	All	Biotic-biotic	Abiotic-biotic	Abiotic-abiotic
<i>Initial</i>	<b>0.006</b>	0.366	<b>0.008</b>	<b>0.008</b>
<i>Y.4</i>	<b>0.017</b>	0.116	<b>0.036</b>	0.063
<i>Y.18</i>	<b>0.001</b>	<b>0.001</b>	<b>0.039</b>	0.213
<i>Y.24</i>	<b>0.001</b>	<b>0.001</b>	<b>0.038</b>	<b>0.029</b>
<i>Y.30</i>	<b>0.001</b>	<b>0.001</b>	<b>0.002</b>	<b>0.029</b>
<i>Target</i>	<b>0.001</b>	<b>0.001</b>	<b>0.002</b>	0.497

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**Table S5:** Effect of time since restoration on correlation-based interactions within plant, soil nematode, fungal and prokaryotic communities and soil abiotic properties. Network analyses were based on Spearman rank correlations ( $\rho$ :  $|0.4501|$ ; also see Fig. 2); # = number of significant interactions;  $\Sigma$  = Connectedness (summed interaction strengths); Cnct. = Connectance (proportion of significant interactions of all possible interactions, biotic: 22, abiotic: 50); *Initial* = intensively managed grasslands; Y.4-30 = restored grasslands; *Target* = semi-natural grasslands.

	Plants			Nematoda			Fungi			Prokaryotes			Soil		
	#	$\Sigma$	Cnct.	#	$\Sigma$	Cnct.	#	$\Sigma$	Cnct.	#	$\Sigma$	Cnct.	#	$\Sigma$	Cnct.
<i>Initial</i>	11	7.6	50.0	11	8.4	50.0	10	6.5	45.5	5	3.6	22.7	27	20.5	54.0
Y.4	7	3.8	31.8	12	8.1	54.5	6	3.4	27.3	14	9.8	63.6	21	14.7	42.0
Y.18	16	12.6	72.7	16	12.2	72.7	18	13.1	81.8	18	12.8	81.8	24	17.5	48.0
Y.24	17	12.9	77.3	16	12.4	72.7	14	10.8	63.6	17	13.5	77.3	23	16.0	46.0
Y.30	19	14.2	86.4	13	9.6	59.1	14	9.1	63.6	17	12.7	77.3	27	19.1	54.0
<i>Target</i>	15	10.7	68.2	11	6.9	50.0	15	11.7	68.2	18	13.2	81.8	30	20.0	60.0