Competitive ability of native and alien plants: effects of residence time and invasion status

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Supplementary File

Appendix 1: Establishment of targets and neighbours

To establish target individuals, three seeds for *Crepis pulchra*, *Hypochaeris glabra*, *Lapsana communis*, and *Senecio viscosus,* and five seeds for *Pulicaria vulgaris* were added to the centre of each pot. A species-specific number of neighbour seeds was sown around the target seeds. To determine the required number of seeds to be sown for each neighbour species, we used data on the average biomass production (in low intraspecific competition: 6 individuals were transplanted in 50L-pots) and establishment rates of the same species (and populations) from a previous experiment in 2016 (Brendel et al. 2021). Given the size of our pots, we aimed for the number of neighbour individuals to range between two and ten. Using this basis, we calculated a reference value for the neighbour biomass: the median of the average biomass at population-level across all Asteraceae species multiplied with half of the maximum number of neighbour individuals per pot we aimed for (i.e., five). In this way, we guaranteed that for each Asteraceae species, no more than ten individuals were needed to reach this reference biomass. Since competition was initiated from seeds, we multiplied the number of individuals per population with the respective establishment rate, which resulted in a species-specific amount of seeds for the neighbours that entered the pots (see Table S1).

If a target did not germinate, we transplanted a back-up seedling from additional germination trays established in the greenhouse. Because we aimed to have similar starting sizes compared to the seedlings sown from seed in case transplanting was necessary, these additional germination trays were established two weeks after sowing into pots due to the faster germination and growth rates in the greenhouse. If a neighbour did not germinate, neighbour seeds were re-sown. In the nutrient-poor soil type, 204 of a total of 615 pots thus had either transplanted targets (101 pots) or re-sown neighbours (88 pots) or both (15 pots); for the nutrient-rich soil type it was 44 of 168 pots respectively (28 transplanted targets, 12 re-sown neighbours, 4 both).

Table S1. The 47 Asteraceae species (nomenclature according to the Plant List, http://www.theplantlist.org, Kalwij 2012*) and their seed source (F1: seed material collected from wild populations or obtained from botanical gardens in 2015; F2: seeds initially originated from wild populations or botanical gardens and collected from mother plants that were grown for one generation in monoculture pots during 2016), the number of pots per species (only interspecific competition with target species shown; for the nutrient-poor and nutrient-rich soil), the average biomass (dry mass in g) per individual (n = number of individual plants used to calculate the average), the number of individuals needed to reach the reference neighbour biomass (21.38 g; for species with higher individual biomass than the reference biomass, the number of individuals was fixed at 2), the average establishment rate (n = number of pots used to calculate the average), and the number of seeds, after accounting for the average establishment rate, that entered the pots to initiate interspecific competition.

Species (seed source)	Pots (nutrient-poor, nutrient-rich soil)	Average biomass per individual	Number of individuals	Average establishment rate	Number of seeds per pot
Anthemis arvensis L. (F2)	11, 4	7.04 (n = 4)	3	0.40 (n = 2)	8
Anthemis cotula L. (F2)	15, 4	2.13 (n = 3)	10	0.50 (n = 2)	20
Artemisia annua L. (F2)	16, 3	6.57 (n = 4)	3	0.50 (n = 2)	6
Bidens ferulifolia (Jacq.) Sweet (F2)	17, 3	4.62 (n = 6)	5	0.50 (n = 2)	10
Bidens pilosa L. (F2)	14, 6	11.32 (n = 4)	2	0.53 (n = 2)	4
Bidens tripartita L. (F2)	15, 4	1.92 (n = 12)	10	0.15 (n = 100) †	67
Calendula arvensis M.Bieb. (F2)	17, 3	4.65 (n = 4)	5	0.58 (n = 2)	9
Calendula officinalis L. (F2)	17, 3	5.75 (n = 4)	4	0.35 (n = 2)	11
Callistephus chinensis (L.) Nees (F2)	13, 6	3.23 (n = 4)	7	0.10 (n = 2)	70
Carthamus lanatus L. (F2)	10, 3	41.16 (n = 4)	2	0.23 (n = 4)	9
Carthamus tinctorius L. (F2)	0, 5	1.99 (n = 4)	10	0.19 (n = 4)	52
Centaurea diffusa Lam. ($F1_{wild}$)	15, 5	6.78 (n = 4)	3	0.45 (n = 2)	7
Centaurea solstitialis L. (F2)	14, 5	12.95 (n = 4)	2	0.16 (n = 4)	13
Cosmos bipinnatus Cav. (F2)	14, 3	13.80 (n = 6)	2	0.38 (n = 2)	5
Cota austriaca (Jacq.) Sch.Bip. (F2)	16, 3	3.53 (n = 8)	6	0.57 (n = 3)	11
Crepis capillaris (L.) Wallr. (F2)	12, 6	4.26 (n = 4)	5	0.60 (n = 2)	8
Crepis pulchra L. (F2)	11, 4	3.79 (n = 6)	6	0.48 (n = 4)	13
Crepis setosa Haller f. (F2)	16, 4	2.38 (n = 6)	9	0.54 (n = 6)	17
Cyanus segetum Hill. (F2)	14, 6	4.28 (n = 10)	5	0.45 (n = 4)	11
Dittrichia graveolens (L.) Greuter (F2)	10, 1	11.08 (n = 4)	2	0.48 (n = 2)	4
Erigeron annuus (L.) Pers. ($F1_{wild}$)	13, 2	3.71 (n = 12)	6	0.23 (n = 2)	27

Erigeron canadensis L. ($F1_{wild}$)	15, 3	6.93 (n = 4)	3	0.43 (n = 2)	7
Erigeron sumatrensis Retz. ($F1_{wild}$)	5, 5	9.11 (n = 12)	2	0.42 (n = 6)	5
Filago arvensis L. (F2)	5, 2	8.66 (n = 6)	3	0.50 (n = 2)	6
Galinsoga parviflora Cav. (F2)	15, 5	6.97 (n = 6)	3	0.48 (n = 2)	6
Galinsoga quadriradiata Ruiz & Pav. (F2)	14, 4	2.84 (n = 4)	8	0.75 (n = 2)	11
Glebionis coronaria (L.) Cass. ex Spach (F2)	17, 2	2.35 (n = 6)	9	0.30 (n = 2)	30
Glebionis segetum (L.) Fourr. (F2)	6, 1	12.88 (n = 4)	2	0.33 (n = 2)	6
Gnaphalium uliginosum L. (F2)	4, 0	4.65 (n = 6)	5	0.35 (n = 4)	14
Guizotia abyssinica (L.f.) Cass. (F2)	17, 3	8.34 (n = 6)	3	0.30 (n = 2)	10
Helminthotheca echioides (L.) Holub (F2)	15, 4	7.97 (n = 4)	3	0.70 (n = 2)	4
Hypochaeris glabra L. (F2)	14, 2	2.07 (n = 6)	10	0.56 (n = 6)	18
Iva xanthiifolia Nutt. (F2)	14, 3	2.73 (n = 2)	8	0.10 (n = 2)	80
Lactuca serriola L. ($F1_{wild}$)	16, 4	24.86 (n = 4)	2	0.40 (n = 2)	5
Lapsana communis L. (F2)	11, 5	3.86 (n = 4)	6	0.50 (n = 2)	12
Matricaria chamomilla L. (F2)	11, 2	4.96 (n = 4)	4	0.50 (n = 2)	8
Matricaria discoidea DC. (F2)	16, 1	3.49 (n = 4)	6	0.45 (n = 2)	14
Pulicaria vulgaris Gaertn. (F2)	13, 3	6.05 (n = 4)	4	0.33 (n = 2)	12
Rudbeckia hirta L. ($F1_{Dresden}$)	13, 6	7.54 (n = 6)	3	0.40 (n = 2)	8
Sanvitalia procumbens Lam. (F2)	15, 3	4.59 (n = 4)	5	0.48 (n = 2)	11
Senecio viscosus L. (F2)	14, 1	4.28 (n = 4)	5	0.70 (n = 2)	7
Senecio vulgaris L. (F2)	11, 4	2.28 (n = 4)	9	0.50 (n = 2)	18
Sigesbeckia serrata DC. (F2)	12, 6	6.01 (n = 12)	4	0.10 (n = 6)	40
Silybum marianum (L.) Gaertn. (F2)	14, 6	4.08 (n = 12)	5	0.15 (n = 4) ‡	33
Sonchus asper (L.) Hill (F2)	15, 5	2.39 (n = 4)	9	0.48 (n = 2)	19
Sonchus oleraceus (L.) L. (F2)	16, 2	4.00 (n = 4)	5	0.35 (n = 2)	14
Tripleurospermum inodorum (L.) Sch.Bip. (F2)	17, 3	14.19 (n = 4)	2	0.35 n = 2)	6

*Kalwij JM (2012) Review of 'The Plant List, a working list of all plant species'. Journal of Vegetation Science 23: 998–1002.

† germination rate (of 100 seeds) measured under greenhouse conditions in 2015

‡ average establishment rate taken from different populations of the same species

Table S2. Linear regressions of species-specific competitive effects of neighbours on the five native target species. Slope (indicating competitive effect), standard error of the slope (used for weighing), R-squared and results of F-test (F-test statistic, degrees of freedom [whereby sample sizes are df+2] and *P*-values) are shown.

Species	**Slope**	**Standard error**	**R-squared**	**F**	**df**	***P*-value**
Anthemis arvensis	-0.700	0.118	79.7	35.3	9	<0.001
Anthemis cotula	-0.849	0.235	50.2	13.1	13	0.003
Artemisia annua	-0.777	0.096	82.5	65.9	14	<0.001
Bidens ferulifolia	0.325	0.124	31.4	6.9	15	0.019
Bidens pilosa	-0.318	0.176	21.3	3.3	12	0.096
Bidens tripartita	-1.048	0.316	45.8	11.0	13	0.006
Calendula arvensis	-0.799	0.315	30	6.4	15	0.023
Calendula officinalis	-0.683	0.167	52.7	16.7	15	0.001
Callistephus chinensis	0.043	0.178	0.5	0.1	11	0.813
Carthamus lanatus	-0.581	0.194	52.9	9.0	8	0.017
Centaurea diffusa	-1.033	0.420	31.8	6.1	13	0.029
Centaurea solstitialis	-0.461	0.224	26.1	4.2	12	0.062
Cosmos bipinnatus	-0.293	0.113	35.9	6.7	12	0.024
Cota austriaca	-0.354	0.361	6.4	1.0	14	0.343
Crepis capillaris	-1.656	0.874	26.4	3.6	10	0.087
Crepis pulchra	-0.296	1.169	0.7	0.1	9	0.806
Crepis setosa	-0.861	0.160	67.3	28.8	14	<0.001
Cyanus segetum	-0.881	0.236	53.8	14.0	12	0.003
Dittrichia graveolens	-0.513	0.192	47.2	7.1	8	0.028
Erigeron annuus	-0.864	0.231	56.1	14.1	11	0.003
Erigeron canadensis	-1.132	0.268	57.8	17.8	13	0.001
Erigeron sumatrensis	-1.158	0.254	87.4	20.8	3	0.02
Filago arvensis	-0.146	0.499	2.8	0.1	3	0.788
Galinsoga parviflora	-0.904	0.205	59.9	19.4	13	0.001
Galinsoga quadriradiata	-1.207	0.338	51.6	12.8	12	0.004
Glebionis coronaria	-0.497	0.137	46.6	13.1	15	0.003

Glebionis segetum	-0.344	0.309	23.7	1.2	4	0.327
Gnaphalium uliginosum	-0.54	0.669	24.6	0.7	2	0.504
Guizotia abyssinica	-0.412	0.175	26.9	5.5	15	0.033
Helminthotheca echioides	-0.83	0.169	65.1	24.3	13	<0.001
Hypochaeris glabra	-0.899	0.383	31.4	5.5	12	0.037
Iva xanthiifolia	-0.963	0.104	87.7	85.8	12	<0.001
Lactuca serriola	-0.535	0.220	29.6	5.9	14	0.029
Lapsana communis	-1.024	0.171	80	35.9	9	<0.001
Matricaria chamomilla	0.221	0.380	3.6	0.3	9	0.575
Matricaria discoidea	-0.63	0.238	33.3	7.0	14	0.019
Pulicaria vulgaris	-0.818	0.244	50.6	11.3	11	0.006
Rudbeckia hirta	-0.854	0.166	70.7	26.5	11	<0.001
Sanvitalia procumbens	-0.528	0.134	54.4	15.5	13	0.002
Senecio viscosus	-0.442	0.308	14.7	2.1	12	0.177
Senecio vulgaris	-0.848	0.474	26.2	3.2	9	0.107
Sigesbeckia serrata	-0.381	0.122	49.6	9.8	10	0.011
Silybum marianum	-0.916	0.320	40.6	8.2	12	0.014
Sonchus asper	-0.847	0.299	38.1	8.0	13	0.014
Sonchus oleraceus	-0.459	0.285	15.6	2.6	14	0.129
Tripleurospermum inodorum	-0.334	0.099	43.2	11.4	15	0.004

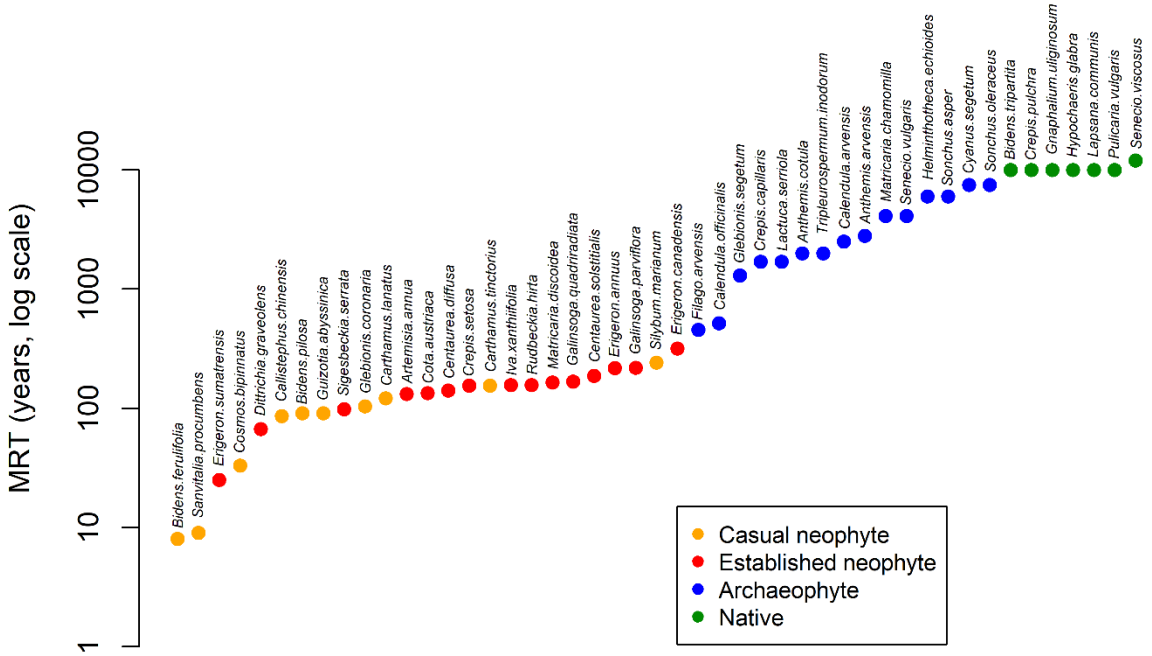

Figure S1. Alien-native continuum of 47 Asteraceae species, with their minimum residence times (MRT) and invasion status in Germany. Information on MRT was extracted from various databases (Sheppard and Schurr 2019). Note that for native species, MRT was usually assigned as 10,000 years (12,000 if there were pollen records from the late glacial) because the selected species likely re-immigrated at some point before the end of the last glacial period (Sheppard and Schurr 2019; Brendel et al. 2021).

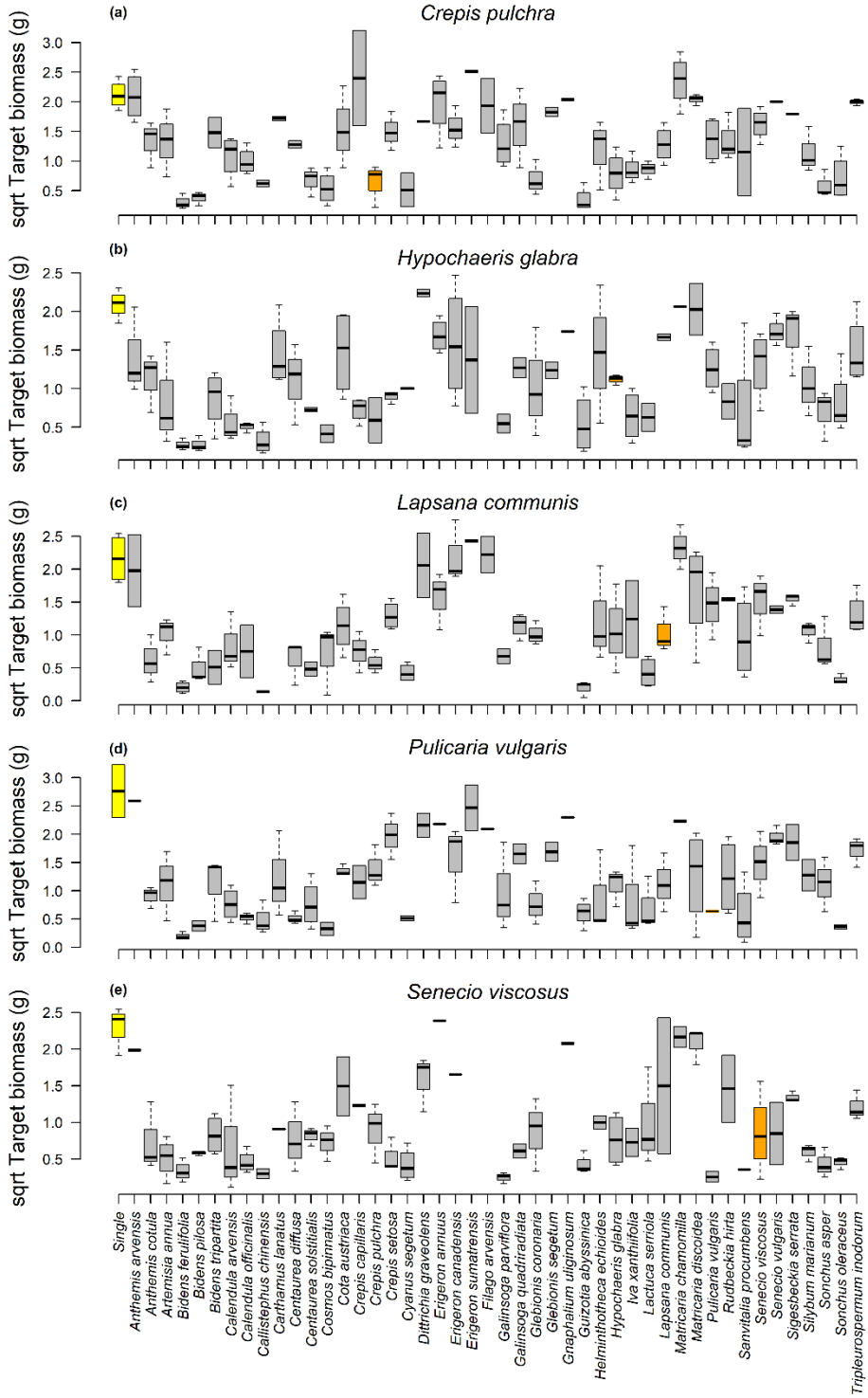

Figure S2. Square-root-transformed target biomass depending on neighbour species in the nutrient-poor soil. (a) *Crepis pulchra* (n = 137), (b) *Hypochaeris glabra* (n = 136), (c) *Lapsana communis* (n = 131), (d) *Pulicaria vulgaris* (n = 126), and (e) *Senecio viscosus* (n = 117). Single target plants are highlighted in yellow, conspecific neighbours (intraspecific competition) in orange.

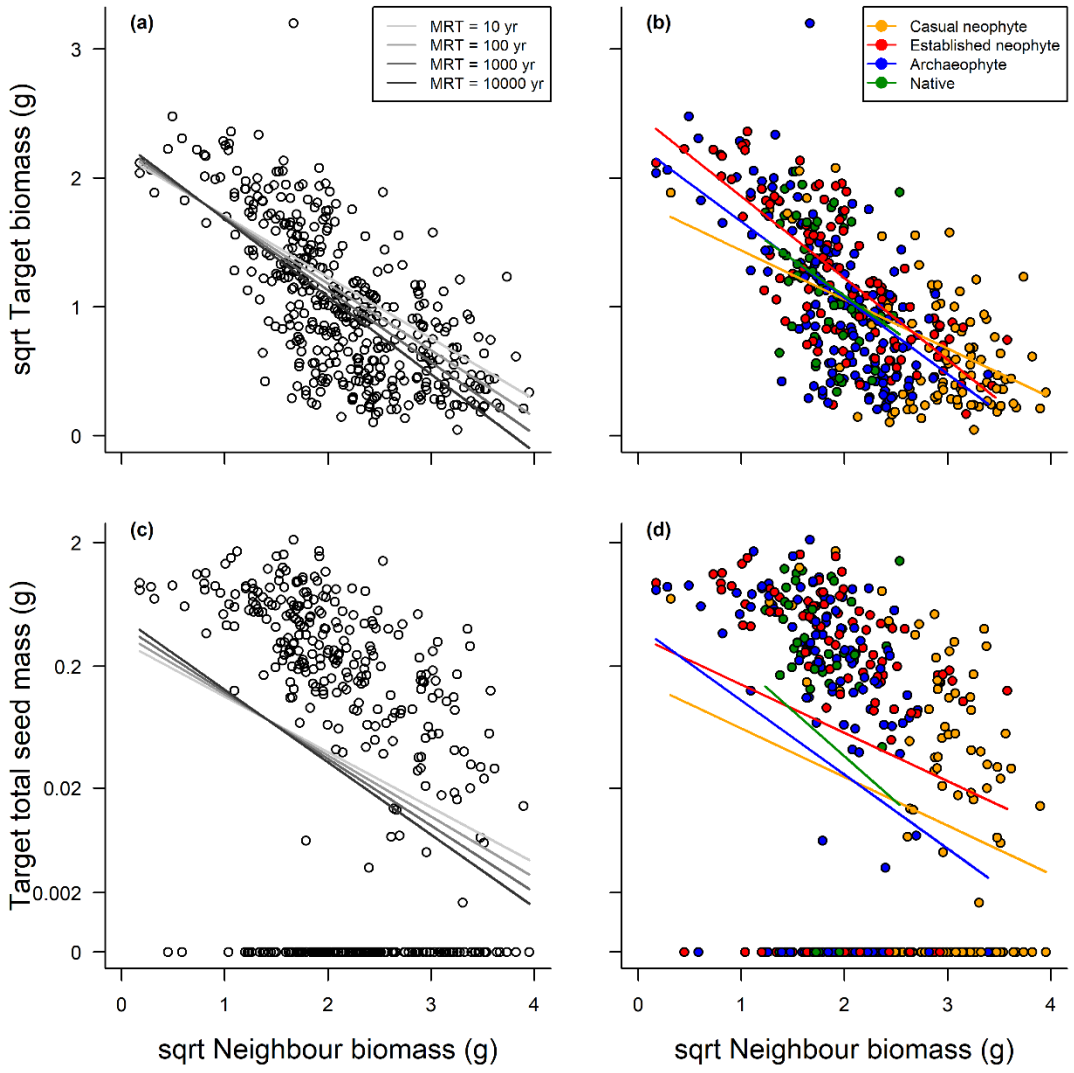

Figure S3. Effects of square-root-transformed neighbour biomass on target performance: (a,b) square-root-transformed aboveground biomass (n = 411), and (c,d) total seed mass (shown on log-scale, n = 411), depending on (a,c) minimum residence time (MRT) or (b,d) invasion status in the control analysis (without transplanted targets and/or re-sown neighbours) for the nutrient-poor soil. To illustrate the interaction between continuous MRT and neighbour biomass in (a,c) a few representative values were chosen.

References

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