

**Can enemy release explain the invasion success of the diploid *Leucanthemum vulgare* in North America?**

*Biological Invasions*

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**Online Resource 1** Populations of *Leucanthemum vulgare* and *L. ircutianum* surveyed for ploidy level, plant performance, herbivore communities, herbivore attack rates and site characteristics in Europe (EU) and the USA

Population code	Country / state	Species	Latitude (°N)	Longitude (°E)	Elevation (m)	Mean annual precipitation (mm)	Mean annual temperature (°C)	Mean minimum temperature of coldest moth (°C)	Mean maximum temperature of warmest month (°C)	Plants analysed <sup>a</sup>
Native range (EU)										
CZ12	Czech Republic	<i>L. ircutianum</i>	50.6947	15.3329	489	1203.5	7.0	-7.2	22.6	2
CZ13	Czech Republic	<i>L. ircutianum</i>	50.6745	15.4082	624	1203.5	7.0	-7.2	22.6	2
CZ17	Czech Republic	<i>L. ircutianum</i>	50.5293	16.1936	430	962.1	6.8	-6.9	21.5	6
CZ18	Czech Republic	<i>L. ircutianum</i>	50.4932	16.3040	572	962.1	6.8	-6.9	21.5	4
CZ19	Czech Republic	<i>L. ircutianum</i>	50.6168	16.3794	523	962.1	6.8	-6.9	21.5	10
CZ20	Czech Republic	<i>L. ircutianum</i>	50.4928	16.2782	524	962.1	6.8	-6.9	21.5	2
CZ21	Czech Republic	<i>L. ircutianum</i>	50.3825	15.7380	281	528.0	9.5	-5.5	26.1	12
CZ23	Czech Republic	<i>L. ircutianum</i>	50.3902	15.6523	329	528.0	9.5	-5.5	26.1	13
CZ24	Czech Republic	<i>L. ircutianum</i>	49.3326	15.6646	608	561.2	7.9	-6.8	24.6	9
CZ26	Czech Republic	<i>L. ircutianum</i>	49.2721	15.8276	575	561.2	7.9	-6.8	24.6	10
CZ27	Czech Republic	<i>L. ircutianum</i>	49.2989	15.8614	593	561.2	7.9	-6.8	24.6	6
CZ29	Austria	<i>L. ircutianum</i>	48.7824	15.0382	522	724.9	7.7	-6.9	24.1	10
CZ31	Austria	<i>L. ircutianum</i>	48.7040	14.8634	596	724.9	7.7	-6.9	24.1	10
CZ32	Austria	<i>L. ircutianum</i>	48.7153	14.7858	709	724.9	7.7	-6.9	24.1	2
CZ33	Czech Republic	<i>L. ircutianum</i>	48.6989	14.6742	719	711.7	8.0	-7.5	24.9	2
CZ35	Czech Republic	<i>L. ircutianum</i>	48.8083	14.3406	587	711.7	8.0	-7.5	24.9	6
FR14	France	<i>L. ircutianum</i>	44.0599	3.3886	840	653.4	10.7	-1.3	26.7	5
FR15	France	<i>L. ircutianum</i>	44.0353	3.3641	734	653.4	10.7	-1.3	26.7	10
FR18	France	<i>L. ircutianum</i>	43.4703	2.5451	305	653.4	10.7	-1.3	26.7	11
FR20	France	<i>L. ircutianum</i>	43.4395	2.3973	600	653.4	10.7	-1.3	26.7	10
FR21	France	<i>L. ircutianum</i>	43.3933	2.4111	733	653.4	10.7	-1.3	26.7	10
FR35	France	<i>L. ircutianum</i>	44.1294	3.4327	1069	653.4	10.7	-1.3	26.7	2
FR36	France	<i>L. ircutianum</i>	44.1108	3.4036	750	653.4	10.7	-1.3	26.7	11

Population code	Country / state	Species	Latitude (°N)	Longitude (°E)	Elevation (m)	Mean annual precipitation (mm)	Mean annual temperature (°C)	Mean minimum temperature of coldest month (°C)	Mean maximum temperature of warmest month (°C)	Plants analysed <sup>a</sup>
Native range (EU, continued)										
FR39	France	<i>L. ircutianum</i>	43.9678	3.1144	808	653.4	10.7	-1.3	26.7	9
FR41	France	<i>L. ircutianum</i>	43.7559	2.9761	744	653.4	10.7	-1.3	26.7	13
FR42	France	<i>L. ircutianum</i>	43.6442	2.8378	1034	653.4	10.7	-1.3	26.7	10
FR43	France	<i>L. ircutianum</i>	43.4340	2.6053	801	653.4	10.7	-1.3	26.7	11
CZ14	Czech Republic	<i>L. vulgare</i>	50.3396	15.9434	263	528.0	9.5	-5.5	26.1	10
CZ15	Czech Republic	<i>L. vulgare</i>	50.2205	15.9068	252	528.0	9.5	-5.5	26.1	8
CZ16	Czech Republic	<i>L. vulgare</i>	50.2933	16.0599	262	528.0	9.5	-5.5	26.1	10
CZ22	Czech Republic	<i>L. vulgare</i>	50.3513	15.7563	265	528.0	9.5	-5.5	26.1	10
CZ25	Czech Republic	<i>L. vulgare</i>	49.2335	15.6693	569	561.2	7.9	-6.8	24.6	10
CZ28	Austria	<i>L. vulgare</i>	48.9174	15.3221	468	724.9	7.7	-6.9	24.1	10
CZ30	Austria	<i>L. vulgare</i>	48.7266	14.9107	511	724.9	7.7	-6.9	24.1	9
CZ34	Czech Republic	<i>L. vulgare</i>	48.6674	14.6271	714	711.7	8.0	-7.5	24.9	2
FR10	France	<i>L. vulgare</i>	43.8922	3.2471	750	653.4	10.7	-1.3	26.7	9
FR12	France	<i>L. vulgare</i>	43.8875	3.2072	693	653.4	10.7	-1.3	26.7	10
FR30	France	<i>L. vulgare</i>	43.9771	3.1556	665	653.4	10.7	-1.3	26.7	5
FR31	France	<i>L. vulgare</i>	43.9725	3.2036	741	653.4	10.7	-1.3	26.7	9
FR32	France	<i>L. vulgare</i>	44.0671	3.2002	483	653.4	10.7	-1.3	26.7	11
FR33	France	<i>L. vulgare</i>	44.1473	3.2680	821	653.4	10.7	-1.3	26.7	10
FR34	France	<i>L. vulgare</i>	44.1301	3.4001	974	653.4	10.7	-1.3	26.7	5
FR38	France	<i>L. vulgare</i>	44.2891	3.3329	848	653.4	10.7	-1.3	26.7	3
FR40	France	<i>L. vulgare</i>	43.8354	3.1737	673	653.4	10.7	-1.3	26.7	10
FR44	France	<i>L. vulgare</i>	43.8404	3.1400	632	653.4	10.7	-1.3	26.7	10
FR45	France	<i>L. vulgare</i>	43.9006	3.0975	589	653.4	10.7	-1.3	26.7	10
FR46	France	<i>L. vulgare</i>	43.9401	3.0089	542	653.4	10.7	-1.3	26.7	9

Population code	Country / state	Species	Latitude (°N)	Longitude (°E)	Elevation (m)	Mean annual precipitation (mm)	Mean annual temperature (°C)	Mean minimum temperature of coldest month (°C)	Mean maximum temperature of warmest month (°C)	Plants analysed <sup>a</sup>
Introduced range (USA)										
US1	WA	<i>L. vulgare</i>	48.0067	-122.4878	29	550.5	10.7	1.4	23.2	10
US2	WA	<i>L. vulgare</i>	48.2092	-122.6239	70	550.5	10.7	1.4	23.2	9
US3	WA	<i>L. vulgare</i>	48.1025	-122.5754	66	550.5	10.7	1.4	23.2	10
US4	WA	<i>L. vulgare</i>	47.3032	-121.2878	750	1166.5	7.1	-6.0	25.1	9
US5	WA	<i>L. vulgare</i>	47.2895	-120.8568	729	529.4	8.0	-5.6	28.2	7
US6	WA	<i>L. vulgare</i>	47.3977	-121.3948	765	1166.5	7.1	-6.0	25.1	10
US7	WA	<i>L. vulgare</i>	47.0585	-123.1941	115	1751.2	11.0	-0.3	26.1	11
US8	WA	<i>L. vulgare</i>	46.9684	-123.6280	5	1751.2	11.0	-0.3	26.1	10
US9	WA	<i>L. vulgare</i>	46.8840	-123.3069	38	1751.2	11.0	-0.3	26.1	10
US10	WA	<i>L. vulgare</i>	46.7895	-123.0171	59	1097.9	11.7	1.0	26.6	10
US11	WA	<i>L. vulgare</i>	46.4430	-123.0845	120	1097.9	11.7	1.0	26.6	10
US12	OR	<i>L. vulgare</i>	45.8375	-123.0376	366	1194.5	9.2	-2.1	25.4	10
US13	OR	<i>L. vulgare</i>	45.8311	-123.2279	223	1194.5	9.2	-2.1	25.4	10
US14	OR	<i>L. vulgare</i>	45.2197	-122.2380	176	1464.5	11.7	0.8	27.6	10
US15	OR	<i>L. vulgare</i>	45.1753	-121.6784	1115	2209.2	5.6	-4.9	21.6	10
US16	ID	<i>L. vulgare</i>	46.6995	-116.5402	835	898.7	6.8	-7.5	28.9	10
US17	ID	<i>L. vulgare</i>	46.8014	-116.4854	880	898.7	6.8	-7.5	28.9	10
US18	ID	<i>L. vulgare</i>	46.9287	-116.7036	785	478.8	7.9	-6.0	29.6	10
US19	ID	<i>L. vulgare</i>	47.0076	-116.8899	803	478.8	7.9	-6.0	29.6	10
US20	ID	<i>L. vulgare</i>	47.8011	-116.9133	663	595.8	9.5	-4.0	29.0	10
US21	ID	<i>L. vulgare</i>	47.6101	-116.6971	784	595.8	9.5	-4.0	29.0	10
US22	MT	<i>L. vulgare</i>	47.3672	-115.2639	931	771.4	4.9	-9.8	29.8	10
US23	MT	<i>L. vulgare</i>	46.9191	-113.9082	1197	594.1	8.0	-7.9	30.1	10
US24	MT	<i>L. vulgare</i>	46.8734	-113.6148	1128	319.2	4.9	-14.9	30.0	10
US25	MT	<i>L. vulgare</i>	47.2028	-113.5066	1199	508.2	5.8	-12.2	29.8	10

Population code	Country / state	Species	Latitude (°N)	Longitude (°E)	Elevation (m)	Mean annual precipitation (mm)	Mean annual temperature (°C)	Mean minimum temperature of coldest month (°C)	Mean maximum temperature of warmest month (°C)	Plants analysed <sup>a</sup>
Introduced range (USA, continued)										
US26	MT	<i>L. vulgare</i>	47.5324	-113.7376	1224	563.3	6.0	-11.0	27.1	11
US27	MT	<i>L. vulgare</i>	47.3155	-114.1262	893	389.9	8.7	-7.5	30.7	10
US28	MT	<i>L. vulgare</i>	47.3221	-115.0760	887	476.8	7.6	-7.5	31.3	10
US29	MT	<i>L. vulgare</i>	47.5898	-115.3633	774	504.3	9.5	-5.5	32.5	10
US30	MT	<i>L. vulgare</i>	47.0134	-113.0673	1291	306.7	3.7	-16.1	28.5	10
US31	MT	<i>L. vulgare</i>	46.9564	-112.7109	1375	413.4	5.8	-11.8	29.2	10

<sup>a</sup> Number of plants/population from which seeds were analysed with flow cytometry

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**Online Resource 2** Populations of *Leucanthemum vulgare* and *L. ircutianum* sampled by colleagues in North America and surveyed for ploidy level only

Province / state	Species	Latitude (°N)	Longitude (°E)	Elevation (m)	Plants analysed <sup>a</sup>
Canada					
AB	<i>L. vulgare</i>	51.2669	-115.9095	1505	4
AB	<i>L. vulgare</i>	51.2526	-115.8502	1487	9
AB	<i>L. vulgare</i>	51.1910	-115.5600	1416	7
AB	<i>L. vulgare</i>	51.1781	-115.7164	1472	7
AB	<i>L. vulgare</i>	51.1446	-115.6911	1497	5
AB	<i>L. vulgare</i>	53.4750	-113.1724	739	10
AB	<i>L. vulgare</i>	53.6444	-113.3586	648	10
AB	<i>L. vulgare</i>	54.5906	-113.2501	624	10
AB	<i>L. vulgare</i>	54.5832	-113.3256	556	10
AB	<i>L. vulgare</i>	54.4596	-113.5026	661	10
AB	<i>L. vulgare</i>	49.4476	-114.4135	1388	10
AB	<i>L. vulgare</i>	49.5016	-114.2797	1283	10
BC	<i>L. vulgare</i>	54.6285	-126.9654	545	10
BC	<i>L. vulgare</i>	55.3561	-127.6802	259	1
BC	<i>L. vulgare</i>	54.0384	-128.6622	4	1
BC	<i>L. vulgare</i>	54.2299	-131.7647	0	1
BC	<i>L. vulgare</i>	50.7071	-120.4132	348	1
BC	<i>L. vulgare</i>	51.2516	-119.9224	579	10
BC	<i>L. vulgare</i>	54.9485	-127.2445	480	10
BC	<i>L. vulgare</i>	49.9606	-116.9567	1669	1
BC	<i>L. vulgare</i>	51.7878	-124.4570	1027	10
BC	<i>L. vulgare</i>	51.9692	-121.8126	768	10
BC	<i>L. vulgare</i>	49.8128	-120.8562	970	10
BC	<i>L. vulgare</i>	50.9490	-120.1447	1062	10
BC	<i>L. vulgare</i>	51.5053	-120.5739	1236	10
BC	<i>L. vulgare</i>	54.7573	-124.2633	857	10
BC	<i>L. vulgare</i>	51.5541	-121.2682	1186	10
BC	<i>L. vulgare</i>	51.1822	-119.8071	1183	10
BC	<i>L. vulgare</i>	49.3740	-117.2438	879	10
BC	<i>L. vulgare</i>	49.9632	-116.9750	1167	10
BC	<i>L. vulgare</i>	53.8195	-123.0850	718	10
BC	<i>L. vulgare</i>	53.8645	-123.2503	796	10
BC	<i>L. vulgare</i>	48.5138	-123.5717	378	10
BC	<i>L. vulgare</i>	48.5690	-123.6368	235	10
ON	<i>L. vulgare</i>	45.5940	-78.3210	418	10

Province / state	Species	Latitude (°N)	Longitude (°E)	Elevation (m)	Plants analysed <sup>a</sup>
Canada (continued)					
ON	<i>L. vulgare</i>	51.2728	-80.6383	8	10
ON	<i>L. vulgare</i>	45.4217	-75.7088	46	2
BC	<i>L. ircutianum</i>	57.8441	-131.3887	230	10
BC	<i>L. ircutianum</i>	51.2355	-120.0287	625	10
USA					
CA	<i>L. vulgare</i>	41.8088	-124.1474	45	1
CO	<i>L. vulgare</i>	39.1667	-105.1655	2246	10
MN	<i>L. vulgare</i>	46.9760	-91.9869	430	10
MN	<i>L. vulgare</i>	46.6206	-92.6027	370	10
MN	<i>L. vulgare</i>	46.1726	-92.8709	340	10
MN	<i>L. vulgare</i>	46.1159	-93.2831	378	1
MN	<i>L. vulgare</i>	44.9469	-92.9353	306	10
MN	<i>L. vulgare</i>	45.2010	-92.8837	298	10
MN	<i>L. vulgare</i>	47.2060	-91.3685	217	10
MN	<i>L. vulgare</i>	46.6421	-92.3842	291	9
MT	<i>L. vulgare</i>	45.5500	-111.0600	1750	10
MT	<i>L. vulgare</i>	46.1766	-113.2605	1953	10
MT	<i>L. vulgare</i>	47.7027	-113.8119	1034	10
MT	<i>L. vulgare</i>	45.6082	-110.9221	1659	10
MT	<i>L. vulgare</i>	47.4333	-114.0980	920	10
MT	<i>L. vulgare</i>	47.6080	-115.3676	771	10
MT	<i>L. vulgare</i>	48.3354	-114.8128	1470	10
MT	<i>L. vulgare</i>	48.0318	-115.8536	709	9
MT	<i>L. vulgare</i>	46.7273	-113.8907	1336	10
MT	<i>L. vulgare</i>	47.2900	-115.1000	800	10
OR	<i>L. vulgare</i>	44.5662	-123.1572	70	10
OR	<i>L. vulgare</i>	46.0349	-122.8936	29	10
WA	<i>L. vulgare</i>	47.3957	-121.3985	815	10
WI	<i>L. vulgare</i>	45.0339	-92.6702	274	10
WI	<i>L. vulgare</i>	45.0731	-92.7586	283	5
WY	<i>L. vulgare</i>	43.4980	-110.8520	1890	10
WY	<i>L. vulgare</i>	43.6300	-109.5200	2200	10
WY	<i>L. vulgare</i>	43.7220	-109.9800	2500	3

<sup>a</sup> Number of plants/population from which seeds were analysed with flow cytometry

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### Online Resource 3

**Table S1** Results of generalized linear mixed models (glmer) and linear mixed models (lme) comparing plant and population traits of *Leucanthemum vulgare* and *L. ircutianum* populations in the native range (Europe). For the comparison of maximum shoot height, the number of shoots per plant, the number of flower heads per plant and the number of flower heads per shoot plant population nested within geographic region (Czech Republic and adjacent parts of Austria vs. southern France) was included as a random effect and for the comparison of the number of shoots, rosettes and flower heads per square meter geographic region was included as a random effect

Response variable	Test	Fixed effect		Random effects			
		<i>Leucanthemum</i> species	<i>P</i>	Region	Population	Residual	Variance
Maximum shoot height (cm)	lme	1.81	0.08	0.002	0.25	0.04	
Number of shoots	glmer	-3.96	< 0.001	<0.001	0.12		
Number of flower heads	glmer	-3.68	0.002	0.007	0.15		
Number of flower heads/shoot	lme	-1.40	0.17	<0.001	0.01	0.09	
Number of shoots/m <sup>2</sup>	lme	0.81	0.42	NA	NA	0.54	
Number of rosettes/m <sup>2</sup>	lme	1.40	0.17	NA	NA	0.81	
Number of flower heads/m <sup>2</sup>	lme	0.40	0.70	NA	NA	0.72	

<sup>a</sup> *t* for linear mixed models and *z* for generalized linear mixed models

**Table S2** Results of generalized linear mixed models (glmer) and linear mixed models (lme) comparing plant and population traits of *Leucanthemum vulgare* populations in the native (Europe) and introduced (North America) ranges. For the comparison of maximum shoot height, the number of shoots per plant, the number of flower heads per plant and the number of flower heads per shoot, plant population nested within geographic region (Czech Republic & adjacent parts of Austria, southern France, Washington & Oregon, Idaho & Montana) was included as random effect and for the comparison of the number of shoots, rosettes and flower heads per square meter geographic region was included as a random effect. *Leucanthemum* species, mean annual temperature, average maximum temperatures of the warmest month, mean annual precipitation, altitude and latitude were included as fixed effects in the full models and the best-fitted models were selected using likelihood ratio tests

Response variable	Fixed effects			Random effects		
	Test	<i>Leucanthemum</i> species t or z	mean temperature t or z	Region Variance	Population Variance	Residual Variance
Maximum shoot height (cm)	lme	-4.63	2.37	0.22	0.15	0.045
Number of shoots	glmer	-0.60		< 0.001	0.25	NA
Number of flower heads	glmer	-3.24		< 0.001	0.32	NA
Number of flower heads/shoot	lme	-5.45		0.002	0.03	0.43
Number of shoots/m <sup>2</sup>	lme	-4.71		< 0.001	NA	0.49
Number of rosettes/m <sup>2</sup>	lme	-6.11		< 0.001	NA	1.20
Number of flower heads/m <sup>2</sup>	lme	-5.36		0.02	NA	0.67

**Table S3** Results of ANOVAS and Kruskal-Wallis tests comparing site characteristics of *Leucanthemum vulgare* and *L. ircutianum* populations in the native range (Europe)

Response variable	Test	d.f.	$F$ or $\chi^2$ <sup>a</sup>	$P$
Vegetation cover (%) <sup>a</sup>	Kruskal-Wallis	1	0.008	0.9
Mean vegetation height (cm) <sup>a</sup>	ANOVA	1,45	0.003	0.9
Number of forb species <sup>a</sup>	ANOVA	1,45	1.57	0.2
Number of grass species	ANOVA	1,45	0.07	0.8
Total number of species <sup>a</sup>	ANOVA	1,45	1.45	0.2
Soil pH	Kruskal-Wallis	1	3.43	0.06

<sup>a</sup>  $F$  for ANOVA,  $\chi^2$  for Kruskal-Wallis tests.

**Table S4** Results of ANOVAS and Kruskal-Wallis tests comparing site characteristics of *Leucanthemum vulgare* populations in the native (Europe) and introduced (North America) ranges.

Response variable	Test	d.f.	For $\chi^2$ <sup>a</sup>	P
Vegetation cover (%) <sup>a</sup>	Kruskall Wallis	1	6.01	0.01
Mean vegetation height (cm) <sup>a</sup>	ANOVA	1,47	15.65	< 0.001
Number of forb species <sup>a</sup>	ANOVA	1,45	78.78	< 0.001
Number of grass species	ANOVA	1,45	21.95	< 0.001
Total number of species <sup>a</sup>	ANOVA	1,45	145.10	< 0.001
Soil pH	Kruskal Wallis	1	0.50	0.45

<sup>a</sup> F for ANOVA,  $\chi^2$ <sup>a</sup> for Kruskal-Wallis tests.

**Table S5** Results of generalized linear mixed models (glmer) comparing root herbivore load and proportions of plants attacked by root herbivores (total attack and attack by the three most abundant root herbivores) for European *Leucanthemum vulgare* and *L. ircutianum*. The full models included plant population nested within geographic region (Czech Republic and adjacent parts of Austria vs. southern France) as random effect and *Leucanthemum* species, the number of shoots per plant, the shoot density and the height of co-occurring vegetation as fixed effects and the best-fitted models were selected using likelihood ratio tests

Response variable	Test	Fixed effects						Random effects			
		<i>Leucanthemum</i> species			Vegetation height			Region	Population	Variance	
		z	P	Number of shoots per plant	z	P	z				P
Proportions of plants attacked by root herbivores	glmer			4.65	< 0.001				0.14		0.56
herbivore load	glmer			9.45	< 0.001				0.06		0.26
Proportions of plants attacked by <i>Diplapion stolidum</i>	glmer	-3.56	< 0.001	3.44	< 0.001				< 0.001		2.13
Proportions of plants attacked by <i>Cyphocleonus trisulcatus</i>	glmer	-2.05	0.04	2.25	0.02				7.70		1.72
Proportions of plants attacked by <i>Oxyna nebulosa</i>	glmer	2.22	0.03			-2.24	0.03		11.01		1.34

**Table S6** Result of generalized linear mixed model comparing the proportions of plants attacked by root herbivores between European and North American *Leucanthemum vulgare* populations. Plant population nested within geographic region (Czech Republic & adjacent parts of Austria, southern France, Washington & Oregon, Idaho & Montana) was included as a random effect

Response variable	Test	Fixed effect		Random effects	
		<i>Leucanthemum</i> species z	P	Region Variance	Population Variance
Proportions of plants attacked by root herbivores	glmer	-3.98	< 0.001	0.11	0.83

## Can enemy release explain the invasion success of the diploid *Leucanthemum vulgare* in North America?

### Biological Invasions

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### Online Resource 4

**A** Site and management characteristics of *Leucanthemum vulgare* and *L. ircutianum* populations from the native (Europe, EU) and invaded (North America, NA, only *L. vulgare*) range

	<i>L. ircutianum</i> (EU)	<i>L. vulgare</i> (EU)	<i>L. vulgare</i> (NA)
Soil disturbance	0.0%	15.0%	35.5%
Mown	96.3%	75.0%	34.8%
Grazed	18.5%	33.3%	29.0
Total number of populations	27	20	31

**B** Habitat types of *Leucanthemum vulgare* and *L. ircutianum* populations from the native (Europe, EU) and invaded (North America, NA, only *L. vulgare*) range

	<i>L. ircutianum</i> (EU)	<i>L. vulgare</i> (EU)	<i>L. vulgare</i> (NA)
Grassland	22	16	17
Roadside	5	1	5
Forest	0	1	6
Ruderal <sup>a</sup>	0	2	3
Total number of populations	27	20	31

<sup>a</sup> ruderal sites were defined as sites with soil disturbance, but which were not grazed or mown