Oikos

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Appendix 1

Table A1. Co-flowering species observed at three sites (AA, EELR and LF) during *Echinacea*'s flowering season. During each time period (early, mid, and late), pollinators were caught as they visited *Echinacea* in order to quantify their pollen load composition.

	Site AA	Site EELR	Site LF
Early (2–4 July)	*Achillea millefolium* *Amorpha canescens* *Cirsium arvense* *Cirsium flodmanii* *Erigeron strigosus* *Heliopsis helianthoides* *Medicago sativa* *Melilotus officinalis* *Pastinaca sativa* *Pediomelum argophyllum*	*Amorpha canescens* *Carduus acanthoides* *Cirsium flodmanii* *Medicago sativa* *Melilotus officinalis* *Pastinaca sativa* *Potentilla arguta*	*Achillea millefolium* *Amorpha canescens* *Cirsium arvense* *Cirsium flodmanii* *Erigeron strigosus* *Melilotus officinalis* *Taraxacum officinale*
Mid 12–15 July	*Amorpha canescens* *Carduus acanthoides* *Dalea purpurea* *Heliopsis helianthoides* *Medicago sativa* *Melilotus officinalis* *Monarda fistulosa* *Pastinaca sativa* *Pediomelum argophyllum* *Solidago* spp.	*Amorpha canescens* *Carduus acanthoides* *Cirsium arvense* *Dalea candida* *Dalea purpurea* *Erigeron strigosus* *Solidago spp.* *Melilotus officinalis* *Medicago sativa* *Monarda fistulosa* *Pastinaca sativa* *Pediomelum argophyllum* *Potentilla arguta*	*Achillea millefolium* *Amorpha canescens* *Cirsium arvense* *Cirsium flodmanii* *Erigeron strigosus* *Dalea purpurea* *Melilotus officinalis* *Pastinaca sativa* *Potentilla arguta*
Late 18–22July	*Carduus acanthoides* *Cirsium flodmanii* *Dalea purpurea* *Erigeron strigosus* *Heliopsis helianthoides* *Medicago sativa* *Melilotus officinalis* *Monarda fistulosa* *Pediomelum argophyllum* *Potentilla arguta* *Solidago* spp. *Trifolium pratense*	*Cirsium flodmanii* *Dalea purpurea* *Heliopsis helianthoides* *Medicago sativa* *Melilotus officinalis* *Monarda fistulosa* *Pastinaca sativa* *Potentilla arguta* *Solidago* spp.	*Cirsium flodmanii* *Dalea purpurea* *Erigeron strigosus* *Melilotus officinalis* *Pastinaca sativa* *Potentilla arguta* *Solidago* spp.

Table A2. Minimal adequate model coefficients with standard errors for pollinator visitation modeled as a binomial response (Fig. 2, Table 2).

Binomial model of pollinator visitation during 10 minute observation periods			
Term	Predictor type	Value	SE
Intercept		1934.750	471.099
Date	Linear	-0.114	0.028
Density	Linear	-249.100	105.440
EELR	Categorical	-705.658	544.854
ERI	Categorical	-1299.666	523.111
LC	Categorical	-1007.942	571.220
LF	Categorical	-509.666	643.104
RRX	Categorical	1319.866	687.626
SPPE	Categorical	-145.992	540.674
STAPP	Categorical	-428.413	516.773
Date × Density	Linear interaction	0.015	0.006
Date × EELR	Linear-categorical interaction	0.042	0.032
Date × ERI	Linear-categorical interaction	0.076	0.031
Date × LC	Linear-categorical interaction	0.059	0.034
Date × LF	Linear-categorical interaction	0.030	0.038
Date × RRX	Linear-categorical interaction	-0.078	0.040
Date × SPPE	Linear-categorical interaction	0.009	0.032
Date × STAPP	Linear-categorical interaction	0.025	0.030

Table A3. Minimal adequate model coefficients with standard errors for multinomial logistic regression of *Echinacea* pollinator community over time (Fig. 3). Multinomial model features an intercept and slope of change over time for each categorical predictor (pollinator taxon).

Multinomial model of *Echinacea* pollinator community					
Term	Predictor type	Value (intercept)	SE (intercept)	Value (date)	SE (date)
Andrena	Categorical	-1.375	0.592	-0.070	0.086
Augochlorella	Categorical	0.766	0.292	0.074	0.026
Med. Black bee	Categorical	-0.423	0.376	0.057	0.031
Male *Melissodes*	Categorical	-2.541	0.773	0.107	0.047
Sm. Black bee	Categorical	1.255	0.282	-0.003	0.028
Sm. Syrphid	Categorical	-0.710	0.395	0.090	0.030

Table A4. Minimal adequate model coefficients with standard errors of the proportion *Echinacea* pollen in body (A) or scopae (B) pollen, modeled as quasibinomial response (See Fig. 5 & Table 3). Multinomial model features an intercept and slope of change over time for each categorical predictor (pollinator taxon).

(A) Binomial model of proportion of body pollen load composed of *Echinacea* pollen			
Term	Predictor type	Value	SE
Intercept		1453.015	979.164
Date	Linear	-0.085	0.058
Augochlorella	Categorical	2809.666	1441.811
Halictus	Categorical	-487.329	1248.353
Date × *Augochlorella*	Linear-categorical interaction	-0.165	0.085
Date × *Halictus*	Linear-categorical interaction	0.029	0.073

(B) Binomial model of proportion of scopae pollen load composed of *Echinacea* pollen			
Term	Predictor type	Value	SE
Intercept		1356.260	757.440
Date	Linear	-0.080	0.045
Augochlorella	Categorical	3346.900	1609.615
Halictus	Categorical	-633.670	1086.378
Date × *Augochlorella*	Linear-categorical interaction	-0.197	0.095
Date × *Halictus*	Linear-categorical interaction	0.037	0.064

Table A5. Analysis of deviance results from backwards selection procedure for model of proportion of pollen load composed of *Echinacea* pollen in only the first two observation periods (2–13 July). *p*-value is associated with the Wald test F statistic associated with dropping the focal term from the previous model. The last body pollen model tests the site term by comparison with the bolded model, not the immediately previous model. The model shown in bold is the minimal adequate model. The full model included three main effects: d = day-of-year (linear predictor), s = site (categorical predictor, three levels), p = pollinator taxon (categorical predictor, three levels), and two interaction terms.

Model: Body pollen	Test term	Res. Dev.	Res. df	F	*p*-value of dropped term
d + p + s + d*p + d*s		873.09	61		
d + p + s + d*p	d*s	881.30	63	0.3039	0.74
d + p + s	d*p	890.47	65	0.3396	0.71
d + p	s	897.93	67	0.2686	0.77
d	p	945.36	69	1.7631	0.18
1	d	1033.86	70	6.5527	0.01
Model: Scopae pollen					
d + p + s + *d*p* + d*s		835.01	60		
d + *p* + s + d*s	d*p	842.16	62	0.2491	0.78
d + s + *d*s*	p	898.96	64	1.9795	0.15
d + s	d*s	946.78	66	1.6668	0.20
d	s	1075.67	68	4.1874	0.02
s	d	1017.31	68	4.9157	0.03

Table A6. Analysis of deviance results from backwards selection procedure for models of species richness in pooled body and scopae pollen loads. *P*-value is associated with the likelihood ratio test statistic associated with dropping the focal term from the previous model. Bolded model is the minimal adequate model. The full model included three main effects: d = day-of-year (linear predictor), s = site (categorical predictor, three levels), p = pollinator taxon (categorical predictor, three levels), and two interaction terms.

Model	Test term	Res. Dev.	Res. df	χ^2	*p*-value of dropped term
d + p + s + d*p + d*s		67.779	77		
d + p + s + d*p	d*s	68.070	79	0.291	0.86
d + p + d*p	s	70.034	81	1.964	0.37
d + p	d*s	72.919	83	2.884	0.24
d	p	74.595	85	1.677	0.43
1	d	74.882	96	0.286	0.59

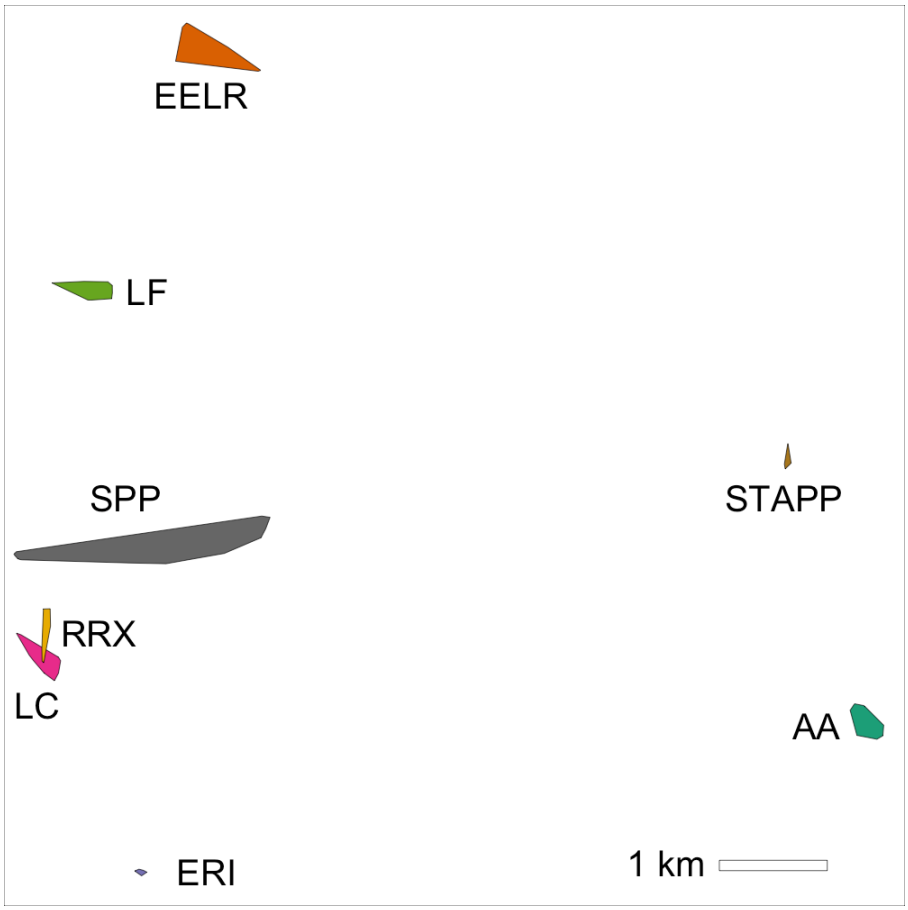

Figure A1. Diagram of shape and locations of the eight remnant populations (Table 1). The study area is in western Minnesota USA (Douglas and Grant counties near 45°49´N, 95°43´W). The shape of each site is the minimal convex polygon of flowering plants (found using R package adehabitatHR; Calenge 2006) in 2016. The size of the polygon is expanded 3x relative to the base map of locations.

Calenge, C. 2006. The package “adehabitat” for the R software: a tool for the analysis of space and habitat use by animals. – Ecol. Model. 197: 516–519.

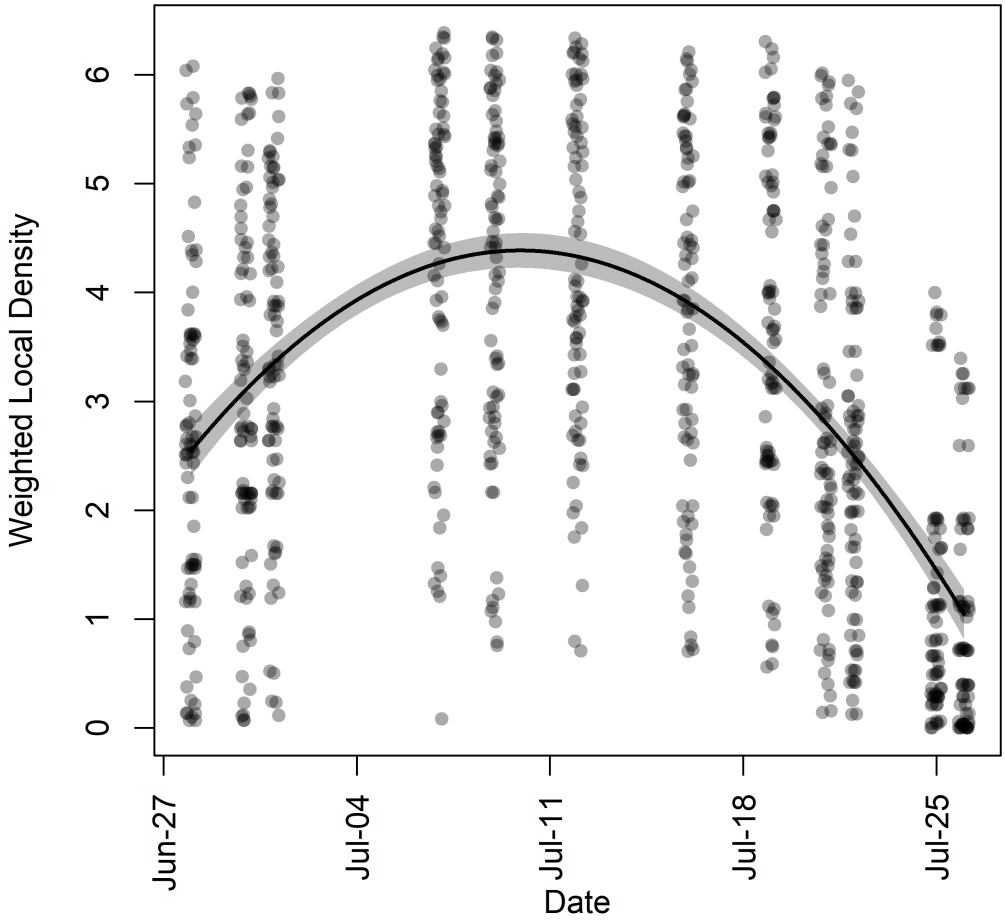

Figure A2. Weighted local density of individuals in relation to date of season. Points are transparent and jittered to show density of overlapping points. The black line shows the prediction of a linear model of weighted local density predicted by a date squared. The gray shaded area represents the 95% confidence interval of the model. We evaluated the relationship between date and observed weighted local density by normalizing (subtracting the mean and dividing by the standard deviation) and squaring date, then testing for correlation with weighted local density. Weighted local density and date were tightly correlated (Pearson's $r = –0.42$, $p < 0.0001$, $n = 938$). The negative correlation coefficient indicates that weighted local density reflects a mid-season peak in flowering density.

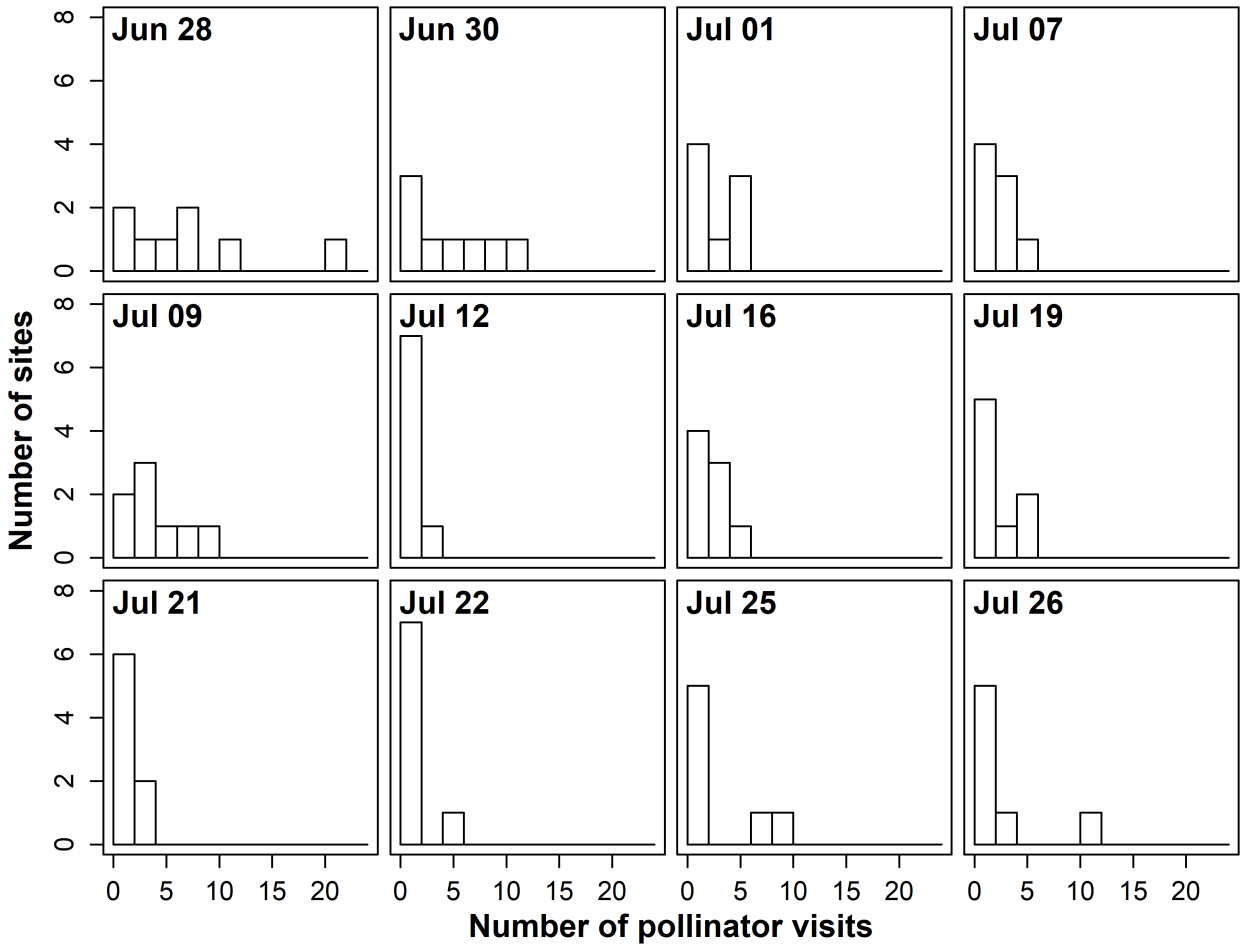

Figure A3. Histograms of the total number of pollinator visits at the eight remnant sites for each of the twelve observation days.

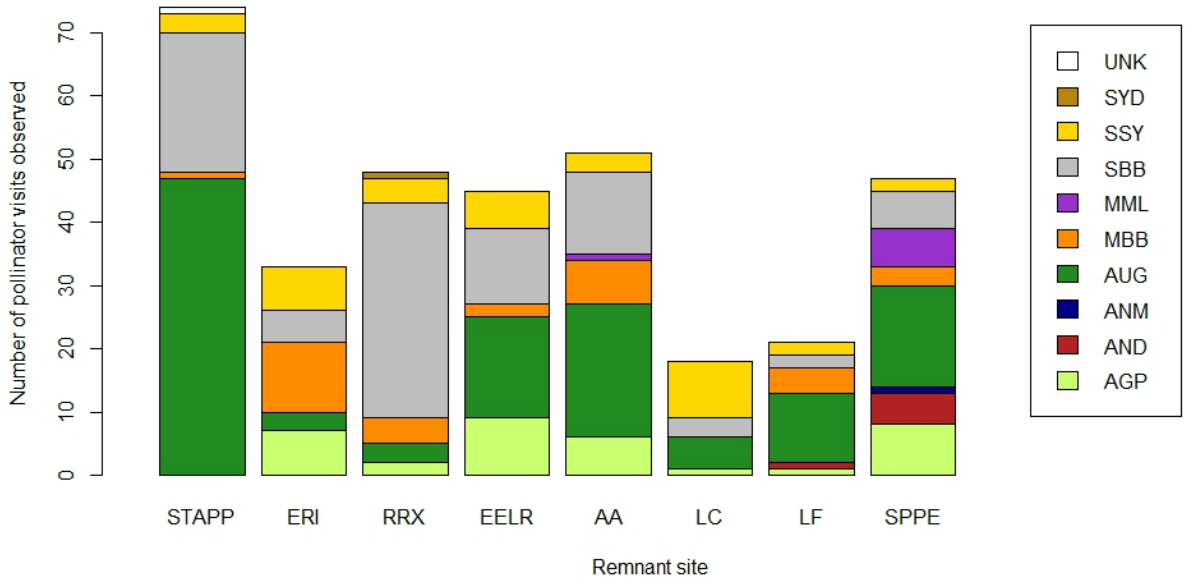

Figure A4. Observed total pollinator visits for each of the eight remnant sites. The sites are arranged by number of flowering plants (smallest to largest; Table 1). No clear relationship exists between number of flowering plants and pollinator visitation rate. The pollinator taxa abbreviations are as follows: AGP = *Agapostemon virescens*, AND = female *Andrena rudbeckia;* ANM = male *Andrena rudbeckia,* AUG =*Augochlorella aurata*, MBB = medium black bees- composed of *Melissdoes* and *Halictus* spp., MML = male *Melissodes* spp., SBB= small black bees- composed of *Ceratina* and *Lasioglossum* spp., SSY = small Syrphidae flies, SYD = large Syrphidae flies, and UNK = unknown pollinator.

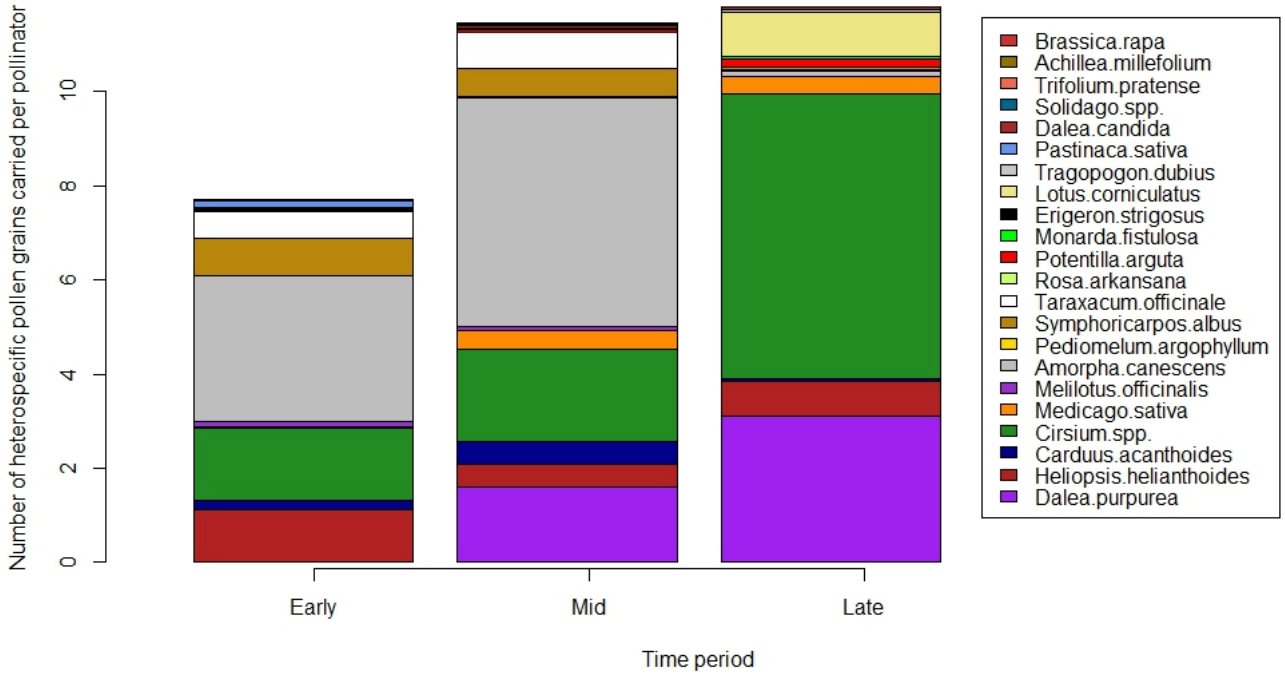

Figure A5. Mean number of heterospecific pollen grains carried by pollinators at three sites (AA, EELR and LF; Table 1). Bees were collected between 2–4 July for the early time period (AA n = 21, LF n = 22, EELR n = 14), 12–15 July for the mid time period (AA n = 37, LF n = 37, EELR n = 26), and 18–22 July for the late time period (AA n = 14, LF n = 11, EELR n = 12). Pollen grains were identified to plant species or genus.

Equation A1

We calculated weighted local density for a plant *i* as

$$\sum_{j=1}^{n} e^{-\gamma d_{ij}}$$

where *n* represents the number of nearest neighbors, γ is the rate of exponential decay, and *dij* is the distance between the focal plant and its *j*th nearest neighbor in meters. The rate of exponential decay, γ, represents the reciprocal of average pollen dispersal distance between plants. The parameters *n* and γ were estimated using the methods of least squares to determine the best fit values in predicting empirically observed seed set (Wagenius 2000). Following Wagenius et al. (2007) for our estimates of weighted local density, we use $n = 7$ and $\gamma = 0.13 m^{-1}$.

Wagenius, S. 2000. Performance of a prairie mating system in fragmented habitat: self-incompatibility and limited pollen dispersal in *Echinacea angustifolia*.

Wagenius, S. et al. 2007. Patch aging and the S- Allee effect: breeding system effects on the demographic response of plants to habitat fragmentation. – Am. Nat. 169: 383–397.