Between-year changes in community composition shape species' roles in an Arctic plant-pollinator network: Supplemental material

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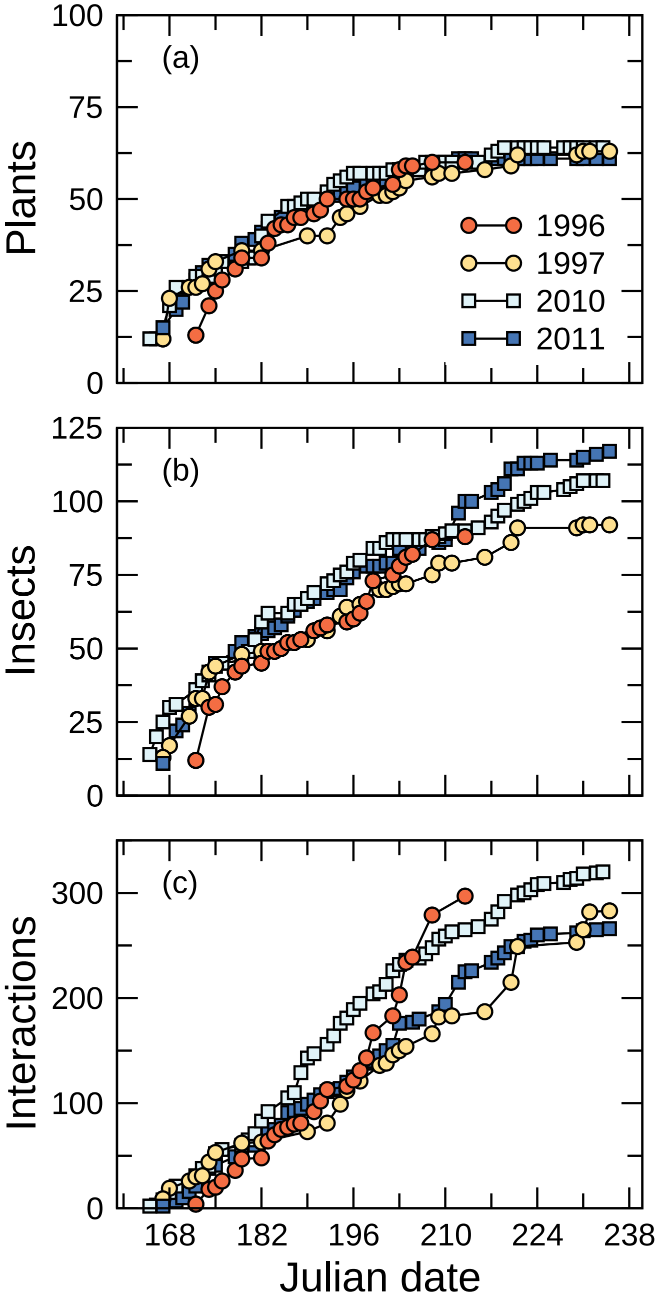
Appendix A1 - Accumulation curves

Figure A1: Accumulation of observed plants, pollinators, and interactions was similar in all years of our dataset, despite the reduced number of sampling days in 1996 and 1997. Based on this, we conclude that number of sampling days did not greatly affect our results.



Appendix A2 - Tentatively dated observations: methods

There were 94 interactions in our dataset which could not be ascribed to a definite date. Of these, 41 were observed in 1996 and the remaining 53 were observed in 1997. The interactions involve five insect species visiting 15 plant species. *Boloria chariclea* visited all 15 plants, *Colias hecla* visited four plant species, *Limnophyes brachytomus* visited three, and *Paraphaenocladius impensus* and *Syngrapha parilis* each visited one. In addition to visiting the most plant species, *Boloria chariclea* was observed far more often than any of the other insects with tentatively-dated observations (79 of the 94 such observations).

Each interaction is associated with a range of possible dates where the plant had been observed flowering and the insect had been observed at the site. Within this range, we used the earliest date that was not associated with a definitively-labelled interaction as the best-guess date for the interaction. This date was used to include the interaction in the monthly networks described in the main text. Because of the uncertainty regarding these dates, we repeated our analyses using two other methods of assigning these interactions. First, we excluded these interactions from the monthly networks entirely. As each interaction was definitively associated with a particular year, however, we included the interactions in the yearly networks. This method underestimated the number of interactions in the 1996 and 1997 monthly networks but presented no risk of assigning an interaction incorrectly. Second, we included the interaction in all networks describing any part of the range of potential dates. This included the yearly networks, as in the other methods, and any relevant monthly networks. This method over-estimates the number of interactions in the 1996 and 1997 monthly networks, but does not exclude any of the pollination interactions that occurred. These three methods of assembling the monthly networks cover a range of conservatism and all have different attendant biases. As described below, all results were qualitatively identical regardless of the method use.

Appendix A3 - Tentatively dated observations: results

Turnover

We observed similar levels of turnover between monthly networks regardless of the method used to account for tentatively-dated observations.

Table A1: Turnover at Zackenberg between monthly webs describing different months in the same year (measured using Whittaker's beta diversity index) when tentatively-dated observations were included in the yearly networks only.

Year	Months		Pollinator turnover	Plant turnover
1996	June	July	0.513	0.463
1996	June	August	0.783	0.727
1996	July	August	0.642	0.538
1997	June	July	0.559	0.368
1997	June	August	0.672	0.514
1997	July	August	0.287	0.224
2010	June	July	0.448	0.463
2010	June	August	0.846	0.733
2010	July	August	0.531	0.404
2011	June	July	0.487	0.476
2011	June	August	0.797	0.643
2011	July	August	0.592	0.364

Table A2: Turnover at Zackenberg between monthly webs describing different months in the same year (measured using Whittaker's beta diversity index) when tentatively-dated observations were included in any network including part of the range of tentative dates.

Year	Months		Pollinator turnover	Plant turnover
1996	June	July	0.513	0.319
1996	June	August	0.692	0.273
1996	July	August	0.594	0.304
1997	June	July	0.536	0.217
1997	June	August	0.672	0.349
1997	July	August	0.273	0.176
2010	June	July	0.448	0.463
2010	June	August	0.846	0.733
2010	July	August	0.531	0.404
2011	June	July	0.487	0.476
2011	June	August	0.797	0.643
2011	July	August	0.592	0.364

Table A3: Turnover at Zackenberg between monthly webs describing the same month in different years (measured using Whittaker's beta diversity index) when tentatively-dated observations were included in the yearly networks only.

Month	Years		Pollinator turnover	Plant turnover
June	1996	1997	0.500	0.280
June	1996	2010	0.529	0.250
June	1996	2011	0.529	0.360
June	1997	2010	0.529	0.200
June	1997	2011	0.569	0.385
June	2010	2011	0.519	0.280
July	1996	1997	0.347	0.111
July	1996	2010	0.421	0.207
July	1996	2011	0.429	0.103
July	1997	2010	0.423	0.222
July	1997	2011	0.453	0.222
July	2010	2011	0.333	0.241
August	1996	1997	0.607	0.412
August	1996	2010	0.765	0.429
August	1996	2011	0.877	0.360
August	1997	2010	0.481	0.381
August	1997	2011	0.516	0.231
August	2010	2011	0.400	0.455

Table A4: Turnover at Zackenberg between monthly webs describing the same month in different years (measured using Whittaker's beta diversity index) when tentatively-dated observations were included in any network including part of the range of tentative dates.

Month	Years		Pollinator turnover	Plant turnover
June	1996	1997	0.500	0.222
June	1996	2010	0.529	0.310
June	1996	2011	0.529	0.400
June	1997	2010	0.529	0.226
June	1997	2011	0.569	0.438
June	2010	2011	0.519	0.280
July	1996	1997	0.333	0.053
July	1996	2010	0.421	0.186
July	1996	2011	0.429	0.119
July	1997	2010	0.410	0.214
July	1997	2011	0.438	0.179
July	2010	2011	0.333	0.241
August	1996	1997	0.552	0.25
August	1996	2010	0.698	0.412
August	1996	2011	0.821	0.355
August	1997	2010	0.481	0.381
August	1997	2011	0.516	0.231
August	2010	2011	0.400	0.455

Change in species' roles

Tentatively-dated observations in yearly webs only

When tentatively-dated observations were not included in the monthly webs, plants' roles in monthly networks varied between years ($F_{1,227}$=2.37, p=0.012). When month and month-year combination were added to the PERMANOVA, plants' roles varied between years, months, and month-year combinations ($F_{1,223}$=2.52, p=0.013; $F_{2,223}$=6.83, p<0.001; and $F_{2,223}$=2.15, p=0.010, respectively). Dispersion of plants' roles was significantly different both between years ($F_{3,225}$=3.32, p=0.021) and month-year combinations ($F_{11,217}$=3.25, p<0.001).

Meanwhile, insects' roles in monthly networks varied between years ($F_{1,455}$=8.51, p<0.001). When month and month-year combination were added to the PERMANOVA, insects' roles varied between years, months, and month-year combinations ($F_{1,451}$=9.00, p<0.001; $F_{2,451}$=12.1, p<0.001; and $F_{2,451}$=3.09, p=0.001, respectively). Dispersion of insects' roles was significantly different between years ($F_{3,453}$=3.37, p=0.018) but not between month-year combinations ($F_{11,445}$=1.04, p=0.414).

Tentatively-dated observations in all webs in range

When tentatively-dated observations were included in all webs covering any of the range of potential dates, plants' roles in monthly webs again varied between years ($F_{1,247}$=6.00, p<0.001). When month and month-year combination were added to the PERMANOVA, plants' roles varied between years, months, and month-year combinations ($F_{1,243}$=6.38, p<0.001; $F_{2,243}$=5.06, p<0.001; and $F_{2,243}$=4.87, p<0.001, respectively). Dispersion of plants' roles was significantly different between years ($F_{3,245}$=4.46, p=0.005) and month-year combinations ($F_{11,237}$=3.46, p<0.001). Regardless of the method used to account for the tentatively-dated observations, our conclusions about change to plants' roles over time remained the same.

Insects' roles in monthly webs, meanwhile, again varied between years ($F_{1,458}$=14.4, p<0.001). When month and month-year combination were added to the PERMANOVA, insects' roles varied between years, months, and month-year combinations ($F_{1,454}$=15.1, p<0.001; $F_{2,454}$=8.28, p<0.001; and $F_{2,454}$=5.30, p<0.001, respectively). Dispersion of insects' roles was significantly different between years ($F_{3,456}$=3.152, p=0.015) but not month-year combinations ($F_{11,448}$=0.764, p=0.676). As with plants' roles, our conclusions about change to insects' roles over time were not affected by the method used to account for the tentatively-dated observations.

Turnover and amount of change in species' roles

Tentatively-dated observations in yearly webs only

When tentatively-dated observations were not included in the monthly webs, the amount of dissimilarity in plants' roles increased with increasing turnover in the insect community but was not affected by turnover in the plant community or the interaction between the two turnover terms ($\beta_{W_{ij}}^{\text{plants}}$=2.01, p=0.328; $\beta_{W_{ij}}^{\text{pollinators}}$=5.06, p=0.010; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=-3.21, p=0.375 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=0.329, p=0.664; $\beta_{W_{ij}}^{\text{pollinators}}$=3.66, p<0.001 when the interaction term was removed). For insects, dissimilarity between roles in different monthly networks increased strongly with turnover in both the plant and insect communities ($\beta_{W_{ij}}^{\text{plants}}$=5.51, p=0.001 and $\beta_{W_{ij}}^{\text{pollinators}}$=4.89, p=0.003, respectively) but decreased with the interaction term ($\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=-7.92, p=0.009). These trends are very similar to those reported in the main text.

Considering only comparisons between webs in the same year, role dissimilarity for plants was not related to the amount of turnover in the plant or insect communities or the interaction between the two turnover terms ($\beta_{W_{ij}}^{\text{plants}}$=-4.82, p=0.346; $\beta_{W_{ij}}^{\text{pollinators}}$=3.51, p=0.343; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=-1.70, p=0.806 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=-3.79, p=0.185; $\beta_{W_{ij}}^{\text{pollinators}}$=4.16, p=0.104 when the interaction term was removed). For insects, too, role dissimilarity between webs in the same year was not related to turnover in the plant community, insect community, or the interaction between them ($\beta_{W_{ij}}^{\text{plants}}$=-1.90, p=0.626; $\beta_{W_{ij}}^{\text{pollinators}}$=3.96, p=0.193; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=-0.996, p=0.860 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=-2.47, p=0.262; $\beta_{W_{ij}}^{\text{pollinators}}$=3.55, p=0.070 when the interaction term was removed). These relationships for insects are very similar to those presented in the main text while for plants the effect sizes are similar to those in the main text but the significance of the effect of insect turnover varied.

Considering only comparisons between webs describing the same month in different years, role dissimilarity for plants increased with increasing turnover in the insect community but was not related to turnover in the plan community or the interaction between the two turnover terms ($\beta_{W_{ij}}^{\text{plants}}$=7.69, p=0.283; $\beta_{W_{ij}}^{\text{pollinators}}$=12.5, p=0.030; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=-18.2, p=0.246 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=-0.404, p=0.811; $\beta_{W_{ij}}^{\text{pollinators}}$=6.40, p<0.001 when the interaction term was removed). Role dissimilarity for insects increased with increasing turnover in the insect community but was not related to turnover in the plant community or the interaction between the two turnover terms ($\beta_{W_{ij}}^{\text{plants}}$=11.3, p=0.065; $\beta_{W_{ij}}^{\text{pollinators}}$=9.52, p=0.050; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=-20.8, p=0.131 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=2.32, p=0.061; $\beta_{W_{ij}}^{\text{pollinators}}$=2.53, p=0.059 when the interaction term was removed). Note that the relationship between dissimilarity in insects' roles was only significant when the interaction term was included in the regression. Both the effect sizes and significances in this case are different from those presented in the main text.

Tentatively-dated observations in all webs in range

When tentatively-dated observations were not included in the monthly webs, the amount of dissimilarity in plants' roles increased with increasing turnover in the insect community but was not affected by turnover in the plant community or the interaction between the two turnover terms ($\beta_{W_{ij}}^{\text{plants}}$=0.648, p=0.776; $\beta_{W_{ij}}^{\text{pollinators}}$=4.41, p=0.012; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=0.677, p=0.868 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=1.01, p=0.178; $\beta_{W_{ij}}^{\text{pollinators}}$=4.65, p<0.001 when the interaction term was removed). For insects, dissimilarity between roles in different monthly networks increased with increasing turnover in the insect community but was not related to turnover in the plant community or the interaction between the two turnover terms ($\beta_{W_{ij}}^{\text{plants}}$=3.66, p=0.043; $\beta_{W_{ij}}^{\text{pollinators}}$=4.66, p=0.002; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=-5.42, p=0.099 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=0.894, p=0.157; $\beta_{W_{ij}}^{\text{pollinators}}$=2.60, p<0.001 when the interaction term was removed). These trends for plants are very similar to those reported in the main text while the trends for insects differ.

Considering only comparisons between webs in the same year, role dissimilarity for plants' was not related to the amount of turnover in the plant or insect communities or the interaction between the two turnover terms ($\beta_{W_{ij}}^{\text{plants}}$=0.338, p=0.937; $\beta_{W_{ij}}^{\text{pollinators}}$=0.965, p=0.692; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=1.05, p=0.870 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=0.990, p=0.530; $\beta_{W_{ij}}^{\text{pollinators}}$=1.29, p=0.376 when the interaction term was removed). For insects, too, role dissimilarity between webs in the same year was not related to turnover in the plant community, insect community, or the interaction between them ($\beta_{W_{ij}}^{\text{plants}}$=0.106, p=0.974; $\beta_{W_{ij}}^{\text{pollinators}}$=0.721, p=0.743; and $\beta_{W_{ij}}^{\text{plants}} \times \beta_{W_{ij}}^{\text{pollinators}}$=1.23, p=0.812 for the regression including the interaction term and $\beta_{W_{ij}}^{\text{plants}}$=0.820, p=0.558; $\beta_{W_{ij}}^{\text{pollinators}}$=1.14, p=0.394 when the interaction term was removed). These relationships for insects are very similar to those presented in the main text while for plants the effect sizes are similar to those in the main text but the significance of the effect of insect turnover varied.

Considering only comparisons between webs describing the same month in different years, role dissimilarity for plants increased with increasing turnover in the insect community but was not related to turnover in the plan community or the interaction between the two turnover terms ($\beta^{\text{plants}}_{W_{ij}}$=4.36, p=0.537; $\beta^{\text{pollinators}}_{W_{ij}}$=14.6, p=0.006; and $\beta^{\text{plants}}_{W_{ij}} \times \beta^{\text{pollinators}}_{W_{ij}}$=-12.4, p=0.419 for the regression including the interaction term and $\beta^{\text{plants}}_{W_{ij}}$=-1.19, p=0.487; $\beta^{\text{pollinators}}_{W_{ij}}$=11.0, p<0.001 when the interaction term was removed). Role dissimilarity for insects increased with increasing turnover in the insect community but was not related to turnover in the plant community or the interaction between the two turnover terms ($\beta^{\text{plants}}_{W_{ij}}$=9.40, p=0.090; $\beta^{\text{pollinators}}_{W_{ij}}$=10.3, p=0.016; and $\beta^{\text{plants}}_{W_{ij}} \times \beta^{\text{pollinators}}_{W_{ij}}$=-19.2, p=0.128 for the regression including the interaction term and $\beta^{\text{plants}}_{W_{ij}}$=1.22, p=0.282; $\beta^{\text{pollinators}}_{W_{ij}}$=4.25, p=0.003 when the interaction term was removed). Note that the relationship between dissimilarity in insects' roles was only significant when the interaction term was included in the regression. Both the effect sizes and significances in this case are different from those presented in the main text.

Appendix A4 - Supplemental figures

Figure A2: Unique positions in the two- to six-species motifs. Two- to four-species motifs are also shown in Fig. 1, *main text*. Positions with white fill can only be occupied by pollinators and positions with black fill can only be occupied by plants. Plants or pollinators indicated by the same number are interchangeable with regard to the motif under consideration.

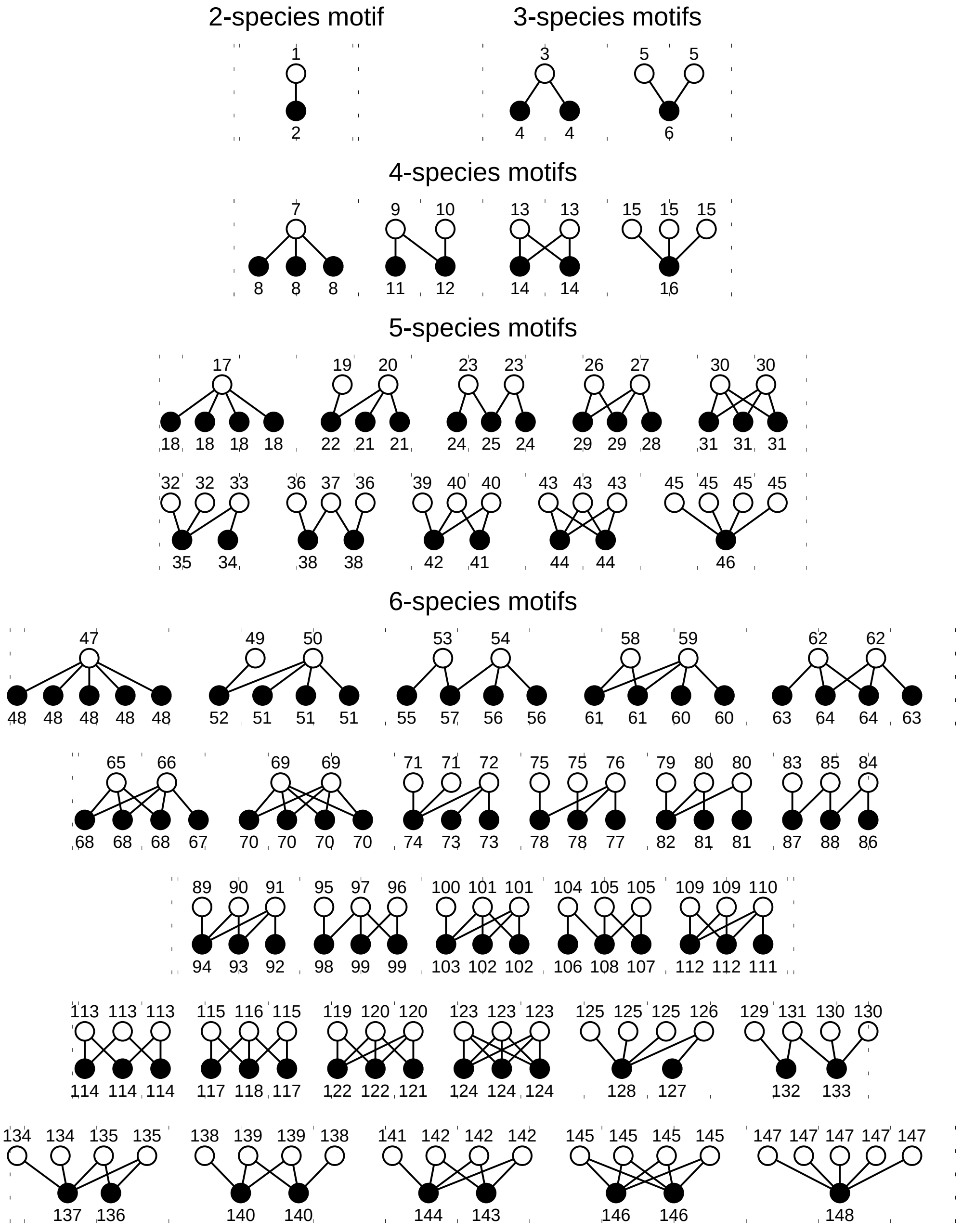


Figure A3: From 1996 to 2011, the composition of the Zackenberg plant-pollinator community changed between years. For each year, we show the number of plants (a) and pollinators (b) that were recorded in the previous year (solid), the number of species detected in the previous year that were not observed in the focal year (no fill), and the number of species that were detected in the focal year but not in the previous year (striped fill). The height of the bar indicates the total number of plants or pollinators observed each year. The majority of plant species were recorded in all four years. The pollinator assemblage, however, both increased in species richness and showed substantial turnover (*Table S5, Appendix S4*).

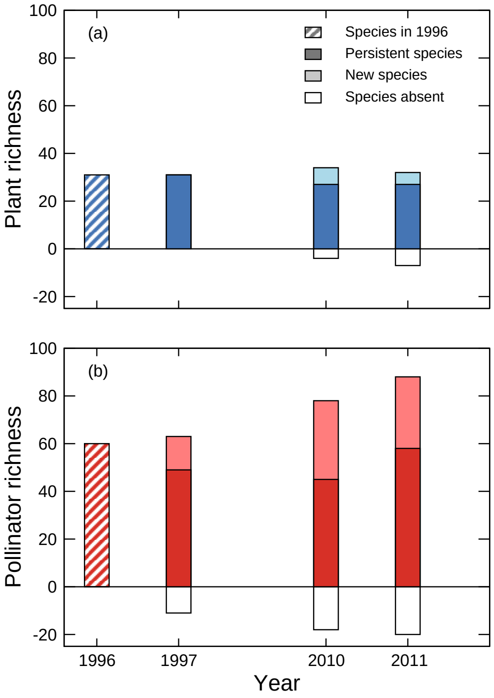


Figure A4: Here we show the loadings of each motif position on the two NMDS axes in Fig. S3. a-b) For both plants and insects, moving from negative to positive values of the second NMDS axis corresponded to decreasing frequencies of 2- and 3-species motifs and increasing frequencies of 6-species motifs. The first NMDS axis was not strongly related to motif size (indicated by shape). c-d) Positive values of the first NMDS corresponded to high frequencies of positions 30, 69, 123 (insects), 44, 124, and 146 (plants) while negative values of the first NMDS axis corresponded to high frequencies of positions 75, 125, 129, 130 (insects), 81, 73, and 127 (plants). Based on these positions, it appears that moving from negative to positive values of the first NMDS axis corresponds to a shift from high frequencies of positions describing specialists to high frequencies of positions describing generalists.

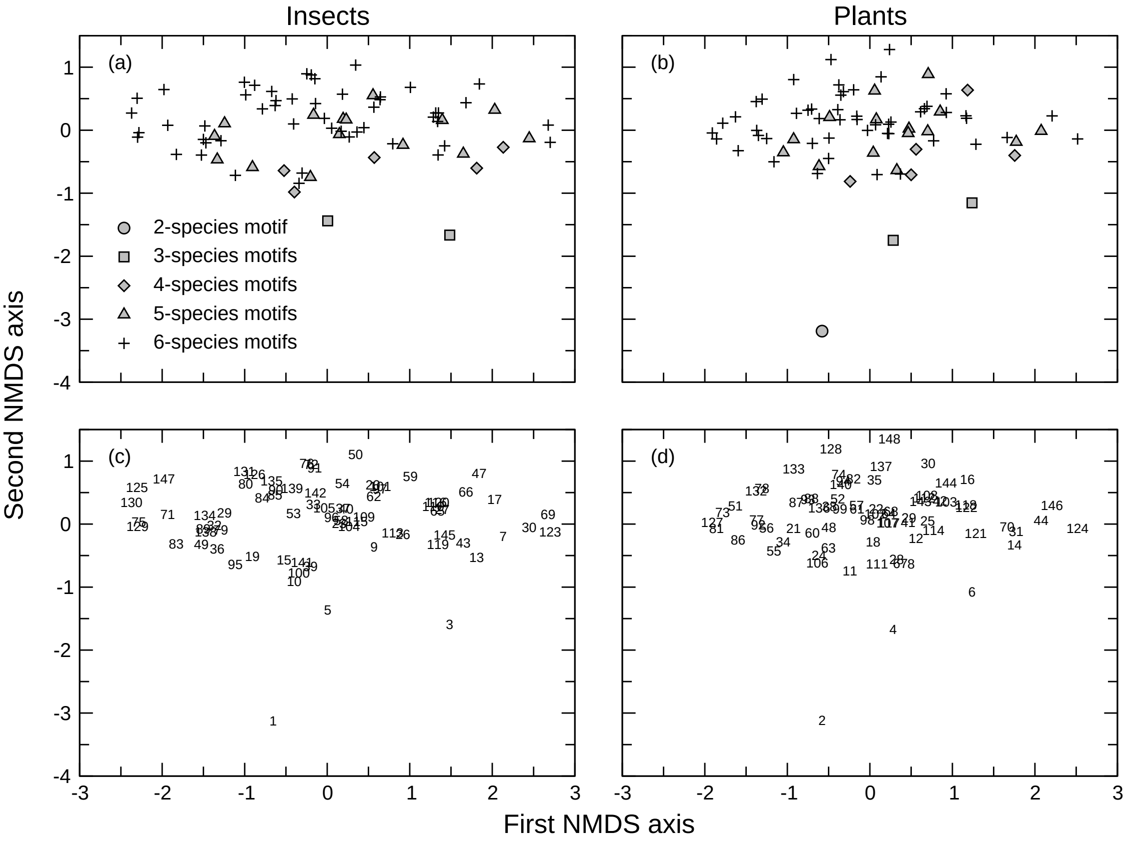


Figure A5: Considering only comparisons between monthly networks describing different months in the same year (i.e., within-year comparisons) dissimilarity in the roles of plants, but not insects, was related to the amount of community turnover. a-b) Dissimilarity in plants' roles increased with increasing turnover in the insect assemblage and was not significantly related to the amount of turnover in the plant assemblage. c-d) Dissimilarity in insects' roles was not significantly related to turnover in the plant or insect assemblages. For both plants and insects, a non-significant interaction term was removed from the model and the model re-fit. In panels (a) and (c) we show the observed relationship between role dissimilarity and insect turnover, while in panels (b) and (d) we show predictions based on the fixed effects of equation (1) (i.e., excluding random effects of species). We show predictions for the minimum and maximum observed plant turnover, as well as moderate values of turnover between the two extremes. Only predictions for combinations of plant and pollinator turnover observed in our data are depicted. Both observed data and prediction lines are coloured along the same scale, according to plant turnover.

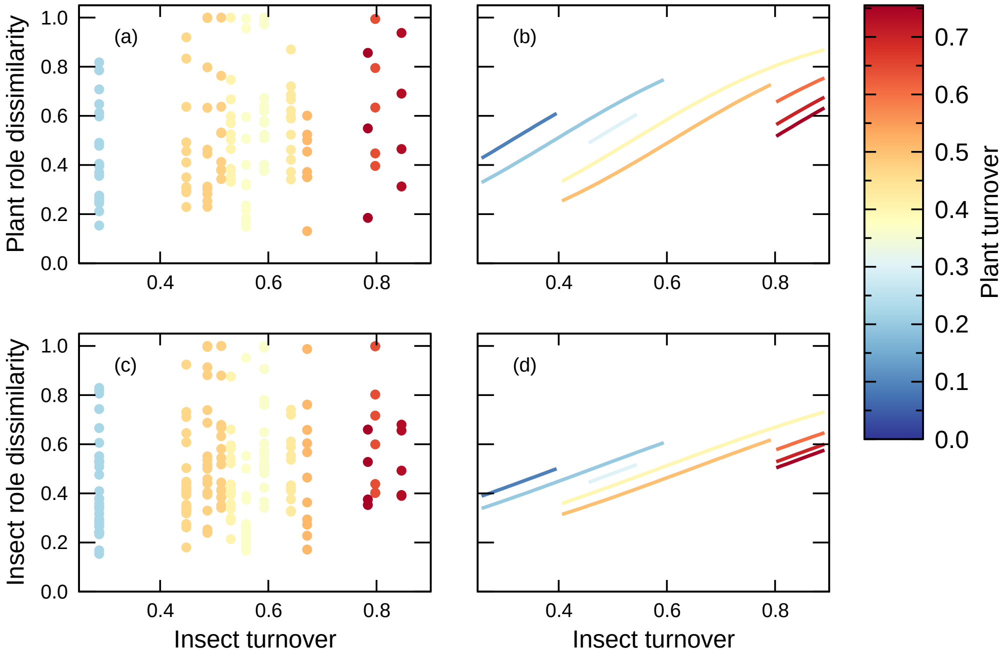
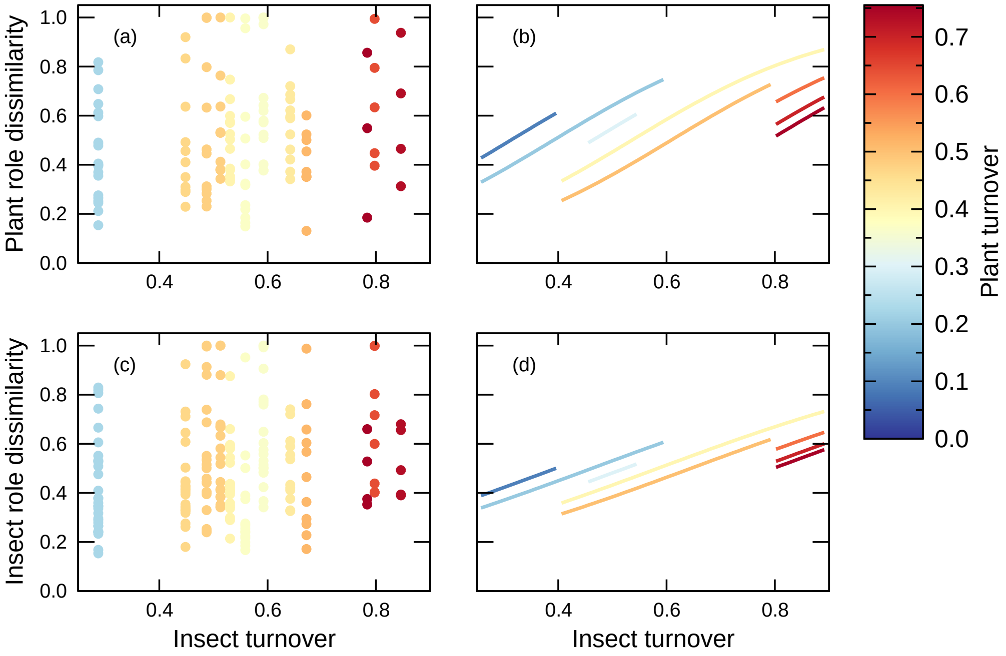


Figure A6: Considering only comparisons between monthly webs describing the same month in different years (i.e., between-year comparisons), dissimilarity in the roles of plants and insects was related to the amount of turnover in the insect assemblage. Only dissimilarity in plants' roles was related to the amount of turnover in the plant community and the interaction between the two turnover terms. a-b) Dissimilarity in plants' roles increased with increasing turnover in the plant and insect assemblages but decreased with the interaction between them. c-d) Dissimilarity in insects' roles increased with increasing turnover in the insect assemblage and was not significantly related to the amount of turnover in the plant assemblage. The interaction term between plant and insect turnover was not significant and was removed from the model. In panels (a) and (c) we show the observed relationship between role dissimilarity and insect turnover, while in panels (b) and (d) we show predictions based on the fixed effects of equation (1) (i.e., excluding random effects of species). We show predictions for the minimum and maximum observed plant turnover, as well as moderate values of turnover between the two extremes. Only predictions for combinations of plant and pollinator turnover observed in our data are depicted. Both observed data and prediction lines are coloured along the same scale, according to plant turnover.



Appendix A5 - Supplemental tables

Table A5: Turnover in the yearly networks at Zackenberg (measured using Whittaker's beta diversity index) was higher among insect pollinators than plants.

Years		Plant turnover	Pollinator turnover
1996	1997	0.000	0.203
1996	2010	0.169	0.391
1996	2011	0.111	0.432
1997	2010	0.169	0.362
1997	2011	0.111	0.417
2010	2011	0.182	0.301

Table A6: Turnover within years in the monthly networks at Zackenberg (measured using Whittaker's beta diversity index) was higher among insect pollinators than plants. Turnover values shown below are for monthly networks including tentatively-dated observations only on networks including the best-guess date for each interaction.

Year	Months		Pollinator turnover	Plant turnover
1996	June	July	0.513	0.476
1996	June	August	0.784	0.750
1996	July	August	0.642	0.429
1997	June	July	0.559	0.368
1997	June	August	0.672	0.514
1997	July	August	0.287	0.224
2010	June	July	0.448	0.463
2010	June	August	0.846	0.733
2010	July	August	0.531	0.404
2011	June	July	0.487	0.476
2011	June	August	0.797	0.643
2011	July	August	0.592	0.364

Table A7: Turnover between years in the monthly networks at Zackenberg (measured using Whittaker's beta diversity index) was higher among insect pollinators than plants. Turnover values shown below are for monthly networks including tentatively-dated observations only on networks including the best-guess date for each interaction.

Month	Years		Pollinator turnover	Plant turnover
June	1996	1997	0.500	0.280
June	1996	2010	0.529	0.250
June	1996	2011	0.529	0.360
June	1997	2010	0.529	0.200
June	1997	2011	0.569	0.385
June	2010	2011	0.519	0.280
July	1996	1997	0.347	0.091
July	1996	2010	0.421	0.186
July	1996	2011	0.429	0.119
July	1997	2010	0.423	0.222
July	1997	2011	0.453	0.222
July	2010	2011	0.333	0.241
August	1996	1997	0.607	0.389
August	1996	2010	0.765	0.467
August	1996	2011	0.877	0.407
August	1997	2010	0.481	0.381
August	1997	2011	0.516	0.231
August	2010	2011	0.400	0.455