Supplementary Information for

Mixed effects of honey bees on pollination function in the Tibetan alpine grasslands

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Supplementary Table 1. Details of study sites and summary of plant and pollinator communities. We selected 48 alpine grassland communities at 21 apiaries (*Apis mellifera*; 1-7 plant communities per apiary), with 24 "bee-near" sites (Close sites; high honey bee density: 1 km from the apiaries) and 24 "bee-far" sites (Far sites; low honey bee density: 3 km away from the apiaries) in 2021 and 2022. The selection criteria for the study sites were an altitude between 2700 and 3400 m above sea level, a size of more than 1 ha, similar native plant communities, and accessibility.

Sites	Years	Latitude	Longitude	Elevation (m)	Distance	Apiary	Honey bee visits	Total visits	No. flowers
BDK	2021	38.2194	100.9508	2822	Far	18	748	1907	12805
BG	2021	37.3586	101.5306	2937	Far	15	239	774	14575
BHXZXXX	2022	36.6606	101.2136	2787	Far	8	344	1062	21252
BYC	2021	36.7072	99.2972	3168	Far	9	0	1234	7381
CHSC	2021	36.5939	101.2208	2950	Close	7	927	1574	18052
DKEC	2022	36.5344	101.1056	3247	Far	3	2	615	15389
DT	2022	36.5736	101.2628	2992	Far	6	39	740	13140
DYC	2021	36.8439	101.0686	2949	Close	11	1681	2872	12968
ELJ	2021	36.5964	100.4236	3229	Close	6	333	458	7418
ET	2022	36.5544	101.2464	3001	Far	6	157	690	17266
FXK	2022	37.6106	101.3181	3212	Far	17	408	3652	33698
GZH	2021	37.1372	100.5511	3262	Close	14	691	812	5923
HCX	2021	37.5953	101.2208	3106	Close	17	1629	2058	18816
HCXSK	2022	36.5197	101.2519	3132	Close	4	275	938	7678
HEG	2021	37.2269	100.4356	3278	Far	14	32	333	4480
HKZ	2021	35.8814	99.9831	3283	Close	2	1928	3537	25769
HMYDJ	2022	36.5878	101.2447	2823	Close	6	3160	3904	28703
HMYDY	2022	36.5928	101.3125	2832	Far	7	41	787	9186
HSW	2022	37.5681	101.2164	3108	Far	17	119	2822	13713
JFWJ	2022	36.5261	101.2600	3132	Close	4	697	1726	9225
JFWY	2022	36.4775	101.2683	3180	Far	4	34	497	12321

Sites	Years	Latitude	Longitude	Elevation (m)	Distance	Apiary	Honey bee visits	Total visits	No. flowers
LHC	2022	36.5742	101.2756	3003	Far	6	132	435	11709
MCTC	2021	36.5414	101.2728	2995	Close	4	739	1464	13483
MDJ	2021	36.4728	101.1436	3145	Far	3	331	922	13424
MJWC	2022	36.5769	101.2439	2903	Far	6	192	2091	27144
MQCC	2021	36.8197	101.5636	2730	Close	10	1708	3164	13549
NGZ	2021	38.5433	100.4978	2795	Far	21	1139	2877	17089
QHHLB	2021	36.5511	100.5811	3250	Close	5	855	992	12143
QHHMSKZ	2021	36.5883	100.4553	3227	Close	6	399	443	18150
QJK	2022	36.6003	101.2306	2925	Close	8	1038	1973	14542
QSZFLZ	2022	37.4706	101.3578	2985	Far	16	54	1737	15378
RYS	2021	36.4453	101.1161	3326	Far	3	142	403	7108
SJC	2021	37.2894	100.2194	3261	Close	14	2441	2615	26954
STL	2021	36.9567	100.9761	3066	Close	12	1005	1377	11106
STMC	2021	37.4622	101.3742	2965	Close	16	1118	1409	10991
STMXG	2022	37.4469	101.3453	3066	Far	16	80	1522	8866
TET	2021	36.4725	101.1214	3298	Close	3	1615	2086	21562
TETC	2022	36.4725	101.2314	3298	Close	3	535	996	15919
XGJ	2021	36.9706	98.5169	3046	Close	13	849	1550	22409
XGL	2021	36.6100	101.2658	2835	Close	7	750	1062	11283
XGLJ	2022	36.6212	101.2958	2835	Close	7	977	1473	12434
XLWTC	2021	36.5914	101.2625	2963	Far	7	825	2135	12624
XLWTY	2022	36.6258	101.2019	3055	Far	8	71	735	9877
XQC	2021	35.1689	100.7444	3401	Close	1	1532	2163	25133
XZC	2021	38.5072	100.6342	2739	Far	20	234	629	3857
YGZ	2021	38.3597	100.8506	2758	Far	19	927	2134	18242
YLMDD	2022	36.6081	101.2850	3149	Far	8	226	1185	9594
ZLDS	2021	36.8508	101.6225	2906	Close	10	1304	2029	4960

Supplementary Table 2. Sampling completeness of pollinator species. We evaluated sampling completeness for the pollinator community using Chao 1 asymptotic species richness estimators. We first estimated the richness of pollinator species accumulated as sampling effort increased up to 100% sampling coverage. We also identified species as dominant (q = 2; Simpson diversity) or common (q =1 Shannon diversity) or rare (q = 0 remaining species) species based on Hill numbers.

	Site	Diversity	Observed	Estimator	s.e.	LCL	UCL	Completeness
1	BDK	Species richness	15	15	0.17	15	15.35	100
2	BDK	Shannon diversity	5.27	5.29	0.14	5.27	5.56	99.64
3	BDK	Simpson diversity	3.84	3.85	0.08	3.84	4.01	99.84
4	BG	Species richness	23	27	5.29	23.56	51.69	85.2
5	BG	Shannon diversity	8.16	8.31	0.39	8.16	9.06	98.22
6	BG	Simpson diversity	5.4	5.43	0.24	5.4	5.91	99.43
7	BHXZXXX	Species richness	35	37.66	3.48	35.38	53.85	92.93
8	BHXZXXX	Shannon diversity	12.67	12.91	0.51	12.67	13.91	98.18
9	BHXZXXX	Simpson diversity	7.06	7.1	0.38	7.06	7.84	99.42
10	BYC	Species richness	39	59.15	17.41	43.66	126.08	65.93
11	BYC	Shannon diversity	4.87	4.99	0.24	4.87	5.45	97.59
12	BYC	Simpson diversity	2.3	2.31	0.09	2.3	2.48	99.91
13	CHSC	Species richness	26	30.5	7.19	26.5	66.89	85.25
14	CHSC	Shannon diversity	4.98	5.03	0.18	4.98	5.38	99.03
15	CHSC	Simpson diversity	2.69	2.7	0.1	2.69	2.88	99.89
16	DKEC	Species richness	29	31	3.74	29.18	51.1	93.56
17	DKEC	Shannon diversity	15.24	15.64	0.6	15.24	16.82	97.49
18	DKEC	Simpson diversity	10.6	10.76	0.53	10.6	11.81	98.43
19	DT	Species richness	45	48.12	3.65	45.51	64.28	93.51
20	DT	Shannon diversity	18.38	19.02	0.95	18.38	20.87	96.67
21	DT	Simpson diversity	8.61	8.7	0.76	8.61	10.19	98.97
22	DYC	Species richness	25	31.25	7.55	25.97	65.12	80.01
23	DYC	Shannon diversity	3.16	3.17	0.08	3.16	3.32	99.46

	Site	Diversity	Observed	Estimator	s.e.	LCL	UCL	Completeness
24	DYC	Simpson diversity	2.27	2.27	0.04	2.27	2.34	99.96
25	ELJ	Species richness	18	20.25	3.39	18.27	37	88.91
26	ELJ	Shannon diversity	3.38	3.46	0.24	3.38	3.93	97.72
27	ELJ	Simpson diversity	1.86	1.86	0.1	1.86	2.06	99.78
28	ET	Species richness	44	48.08	4.04	44.81	64.64	91.52
29	ET	Shannon diversity	18.01	18.69	0.82	18.01	20.3	96.38
30	ET	Simpson diversity	10.13	10.27	0.7	10.13	11.65	98.68
31	FXK	Species richness	62	70.1	7.1	63.84	97.56	88.45
32	FXK	Shannon diversity	15.16	15.31	0.36	15.16	16.02	99
33	FXK	Simpson diversity	7.33	7.34	0.23	7.33	7.79	99.82
34	GZH	Species richness	12	12.17	0.54	12.01	15.53	98.64
35	GZH	Shannon diversity	2.04	2.05	0.1	2.04	2.24	99.27
36	GZH	Simpson diversity	1.37	1.37	0.04	1.37	1.45	99.93
37	HCX	Species richness	23	27.17	4.88	23.67	48.76	84.67
38	HCX	Shannon diversity	2.55	2.57	0.09	2.55	2.73	99.3
39	HCX	Simpson diversity	1.57	1.57	0.04	1.57	1.64	99.94
40	HCXSK	Species richness	16	16.5	1.32	16.03	24.43	96.98
41	HCXSK	Shannon diversity	5.72	5.77	0.18	5.72	6.11	99.13
42	HCXSK	Simpson diversity	4.53	4.55	0.11	4.53	4.77	99.63
43	HEG	Species richness	20	24.49	7.17	20.49	60.8	81.68
44	HEG	Shannon diversity	13.6	14.11	0.64	13.6	15.37	96.39
45	HEG	Simpson diversity	11.38	11.75	0.67	11.38	13.06	96.87
46	HKZ	Species richness	37	37.25	0.73	37.01	41.73	99.33
47	HKZ	Shannon diversity	5.87	5.9	0.16	5.87	6.2	99.47
48	HKZ	Simpson diversity	2.95	2.95	0.06	2.95	3.08	99.93
49	HMYDJ	Species richness	39	49.66	10.27	41.18	91.16	78.53
50	HMYDJ	Shannon diversity	2.74	2.75	0.07	2.74	2.9	99.35

	Site	Diversity	Observed	Estimator	s.e.	LCL	UCL	Completeness
51	HMYDJ	Simpson diversity	1.52	1.52	0.02	1.52	1.56	99.93
52	HMYDY	Species richness	32	49.98	23.59	34.53	159.81	64.03
53	HMYDY	Shannon diversity	16.5	16.99	0.61	16.5	18.18	97.1
54	HMYDY	Simpson diversity	12.53	12.72	0.48	12.53	13.65	98.53
55	HSW	Species richness	38	39	2.32	38.07	52.44	97.44
56	HSW	Shannon diversity	13.79	13.89	0.34	13.79	14.56	99.32
57	HSW	Simpson diversity	7.4	7.42	0.22	7.4	7.85	99.77
58	JFWJ	Species richness	45	53.1	7.09	46.84	80.55	84.75
59	JFWJ	Shannon diversity	8.5	8.64	0.34	8.5	9.3	98.38
60	JFWJ	Simpson diversity	4.34	4.35	0.17	4.34	4.67	99.82
61	JFWY	Species richness	28	38.11	9	30.26	73.19	73.48
62	JFWY	Shannon diversity	6.92	7.21	0.44	6.92	8.07	95.99
63	JFWY	Simpson diversity	4.19	4.22	0.23	4.19	4.67	99.34
64	LHC	Species richness	29	31.99	4.59	29.35	54.81	90.64
65	LHC	Shannon diversity	15.45	16.04	0.85	15.45	17.7	96.32
66	LHC	Simpson diversity	8.41	8.56	0.84	8.41	10.21	98.29
67	MCTC	Species richness	27	27.07	0.3	27	29.07	99.74
68	MCTC	Shannon diversity	6.36	6.42	0.23	6.36	6.88	99.07
69	MCTC	Simpson diversity	3.46	3.46	0.13	3.46	3.71	99.83
70	MDJ	Species richness	23	35.24	13.14	25.2	91.09	65.27
71	MDJ	Shannon diversity	6.04	6.16	0.26	6.04	6.67	98.1
72	MDJ	Simpson diversity	3.85	3.86	0.14	3.85	4.13	99.69
73	MJWC	Species richness	41	41.5	1.32	41.03	49.44	98.8
74	MJWC	Shannon diversity	15.67	15.83	0.4	15.67	16.61	99.01
75	MJWC	Simpson diversity	10.55	10.6	0.26	10.55	11.1	99.54
76	MQCC	Species richness	28	34	7.29	28.93	66.76	82.36
77	MQCC	Shannon diversity	6.08	6.12	0.15	6.08	6.41	99.46

	Site	Diversity	Observed	Estimator	s.e.	LCL	UCL	Completeness
78	MQCC	Simpson diversity	3.15	3.15	0.08	3.15	3.31	99.94
79	NGZ	Species richness	16	16	0.32	16	16.75	100
80	NGZ	Shannon diversity	3.33	3.33	0.07	3.33	3.47	99.73
81	NGZ	Simpson diversity	2.58	2.58	0.04	2.58	2.65	99.92
82	QHHLB	Species richness	20	22.25	3.39	20.27	39.02	89.9
83	QHHLB	Shannon diversity	2.14	2.17	0.09	2.14	2.34	98.85
84	QHHLB	Simpson diversity	1.34	1.34	0.03	1.34	1.41	100
85	QHHMSKZ	Species richness	10	12.99	4.48	10.36	35.09	76.96
86	QHHMSKZ	Shannon diversity	1.68	1.7	0.11	1.68	1.92	98.53
87	QHHMSKZ	Simpson diversity	1.23	1.23	0.04	1.23	1.31	99.92
88	QJK	Species richness	38	50.24	13.15	40.2	106.13	75.63
89	QJK	Shannon diversity	8.04	8.15	0.29	8.04	8.72	98.74
90	QJK	Simpson diversity	3.42	3.42	0.13	3.42	3.68	99.88
91	QSZFLZ	Species richness	43	53.66	10.27	45.18	95.15	80.13
92	QSZFLZ	Shannon diversity	14.51	14.75	0.43	14.51	15.6	98.41
93	QSZFLZ	Simpson diversity	8.93	8.97	0.32	8.93	9.6	99.54
94	RYS	Species richness	25	28.99	5.28	25.56	53.66	86.24
95	RYS	Shannon diversity	10.52	10.92	0.74	10.52	12.37	96.35
96	RYS	Simpson diversity	5.98	6.05	0.51	5.98	7.04	98.76
97	SJC	Species richness	29	41.5	10.68	31.93	82.33	69.89
98	SJC	Shannon diversity	1.51	1.52	0.04	1.51	1.6	99.14
99	SJC	Simpson diversity	1.15	1.15	0.01	1.15	1.17	100
100	STL	Species richness	24	84.46	71.02	33.75	399.06	28.42
101	STL	Shannon diversity	3.08	3.14	0.14	3.08	3.42	97.87
102	STL	Simpson diversity	1.83	1.83	0.06	1.83	1.94	99.95
103	STMC	Species richness	19	28.99	10.28	20.89	71.84	65.53
104	STMC	Shannon diversity	2.53	2.55	0.1	2.53	2.75	99.02

	Site	Diversity	Observed	Estimator	s.e.	LCL	UCL	Completeness
105	STMC	Simpson diversity	1.56	1.56	0.04	1.56	1.64	99.94
106	STMXG	Species richness	45	51	6.48	46.07	78.6	88.24
107	STMXG	Shannon diversity	15.16	15.43	0.53	15.16	16.46	98.27
108	STMXG	Simpson diversity	9.25	9.3	0.34	9.25	9.97	99.45
109	TET	Species richness	26	28	2.65	26.28	40.36	92.86
110	TET	Shannon diversity	3.03	3.05	0.11	3.03	3.25	99.34
111	TET	Simpson diversity	1.77	1.77	0.04	1.77	1.84	100
112	TETC	Species richness	34	51.98	23.6	36.53	161.84	65.41
113	TETC	Shannon diversity	8.03	8.22	0.42	8.03	9.04	97.65
114	TETC	Simpson diversity	3.38	3.39	0.19	3.38	3.76	99.76
115	XGJ	Species richness	41	65.98	24.22	46.07	164.2	62.14
116	XGJ	Shannon diversity	6.25	6.38	0.28	6.25	6.93	97.98
117	XGJ	Simpson diversity	3.05	3.06	0.13	3.05	3.3	99.87
118	XGL	Species richness	28	29.5	2.29	28.17	40.88	94.92
119	XGL	Shannon diversity	4.73	4.79	0.21	4.73	5.2	98.77
120	XGL	Simpson diversity	2.27	2.27	0.08	2.27	2.43	99.91
121	XGLJ	Species richness	32	35.12	3.66	32.51	51.29	91.11
122	XGLJ	Shannon diversity	4.26	4.32	0.19	4.26	4.69	98.77
123	XGLJ	Simpson diversity	2.08	2.08	0.07	2.08	2.22	99.9
124	XLWTC	Species richness	34	40	7.3	34.93	72.89	85.01
125	XLWTC	Shannon diversity	9.05	9.13	0.28	9.05	9.67	99.06
126	XLWTC	Simpson diversity	4.88	4.89	0.17	4.88	5.23	99.82
127	XLWTY	Species richness	41	53.23	13.14	43.2	109.08	77.02
128	XLWTY	Shannon diversity	21.23	22.02	0.92	21.23	23.82	96.41
129	XLWTY	Simpson diversity	14.32	14.59	0.89	14.32	16.33	98.18
130	XQC	Species richness	35	41	6.48	36.07	68.61	85.37
131	XQC	Shannon diversity	4.24	4.28	0.17	4.24	4.61	99.02

	Site	Diversity	Observed	Estimator	s.e.	LCL	UCL	Completeness
132	XQC	Simpson diversity	1.97	1.97	0.06	1.97	2.08	99.95
133	XZC	Species richness	17	20.99	5.28	17.56	45.68	80.98
134	XZC	Shannon diversity	5.53	5.62	0.25	5.53	6.11	98.29
135	XZC	Simpson diversity	3.92	3.94	0.15	3.92	4.24	99.54
136	YGZ	Species richness	20	32.49	17.13	21.66	113.79	61.55
137	YGZ	Shannon diversity	5.28	5.31	0.15	5.28	5.6	99.28
138	YGZ	Simpson diversity	3.67	3.68	0.09	3.67	3.86	99.89
139	YLMDD	Species richness	49	57.09	7.09	50.84	84.54	85.82
140	YLMDD	Shannon diversity	18.39	18.86	0.67	18.39	20.16	97.49
141	YLMDD	Simpson diversity	11.23	11.33	0.5	11.23	12.3	99.13
142	ZLDS	Species richness	19	19.67	1.31	19.06	26.8	96.61
143	ZLDS	Shannon diversity	3.2	3.22	0.1	3.2	3.41	99.53
144	ZLDS	Simpson diversity	2.16	2.16	0.05	2.16	2.26	99.95

Supplementary Table 3. Statistics of all 48 plant-pollinator networks in the Tibetan alpine grasslands. The metrics include 9 network metrics (this is, rate of honey bees, number of pollinator species, number of visits, interaction evenness, interaction diversity, functional complementarity of pollinators, niche overlap of plants, generality of pollinators and vulnerability of plants).

Sites	Rate of honey bees	No. pollinator species	No. plant species	Interaction diversity	Interaction evenness	Niche overlap	Functional complementarity	Generality	Vulnerability
BDK	39.22	15	12	2.53	0.49	0.22	1477.57	3.02	2.56
BG	30.88	23	17	2.78	0.47	0.08	796.67	2.07	2.13
BHXZXXX	32.39	29	19	3.13	0.50	0.06	540.20	1.64	4.98
BYC	0.00	39	13	2.43	0.39	0.19	1330.03	2.42	2.75
CHSC	58.89	26	18	2.49	0.41	0.27	1653.89	2.59	2.18
DKEC	0.33	29	19	3.13	0.50	0.06	540.20	1.64	4.98
DT	5.27	45	15	3.79	0.58	0.08	523.67	2.70	7.19
DYC	58.53	25	17	1.89	0.31	0.24	2713.24	2.32	2.26
ELJ	72.71	18	12	2.53	0.47	0.45	414.52	4.11	2.26
ET	22.75	44	22	3.96	0.58	0.13	513.49	3.48	3.43
FXK	11.17	62	20	3.90	0.55	0.17	2648.39	3.52	5.36
GZH	85.10	12	11	1.99	0.41	0.51	850.72	3.91	1.43
HCX	79.15	23	22	2.87	0.46	0.61	1680.68	7.79	1.88
HCXSK	29.32	16	8	2.25	0.46	0.21	1010.74	1.83	2.16
HEG	9.61	20	11	3.06	0.57	0.10	283.67	1.70	4.46
HKZ	54.51	37	14	2.70	0.43	0.32	3318.02	3.03	3.19
HMYDJ	80.94	39	17	2.33	0.36	0.51	4152.65	4.05	1.90
HMYDY	5.21	32	14	3.58	0.59	0.14	510.71	2.35	5.17
HSW	4.22	38	17	3.45	0.53	0.19	2365.12	2.47	4.85
JFWJ	40.38	45	31	3.53	0.49	0.21	1267.53	4.71	3.51
JFWY	6.84	28	15	2.74	0.45	0.15	492.36	2.41	3.32
LHC	30.34	29	15	3.48	0.57	0.25	313.25	2.52	8.22

Sites	Rate of honey bees	No. pollinator species	No. plant species	Interaction diversity	Interaction evenness	Niche overlap	Functional complementarity	Generality	Vulnerability
MCTC	50.48	27	18	2.86	0.46	0.33	1436.76	3.03	2.85
MDJ	35.90	23	13	2.46	0.43	0.16	810.26	2.08	3.10
MJWC	9.18	41	26	3.94	0.57	0.14	1313.44	3.88	4.30
MQCC	53.98	28	18	2.41	0.39	0.20	3938.60	1.95	2.86
NGZ	39.59	16	14	1.90	0.35	0.32	3469.88	2.61	2.06
QHHLB	86.19	20	11	2.20	0.41	0.79	927.57	4.65	2.05
QHHMSKZ	90.07	10	11	2.25	0.48	0.49	366.01	6.07	1.31
QJK	52.61	38	21	3.43	0.51	0.25	1529.83	4.60	4.71
QSZFLZ	3.11	43	17	3.45	0.52	0.12	1617.46	2.45	4.02
RYS	35.24	25	9	2.97	0.55	0.15	386.47	2.06	6.52
SJC	93.35	29	16	2.14	0.35	0.52	2461.83	5.84	1.34
STL	72.98	24	10	2.15	0.39	0.30	1594.36	2.89	2.15
STMC	79.35	19	20	2.76	0.47	0.55	1025.16	7.82	1.54
STMXG	5.26	45	17	3.46	0.52	0.10	1360.01	2.48	4.68
TET	77.42	26	19	2.50	0.40	0.21	1973.05	4.26	2.17
TETC	53.71	34	18	3.47	0.54	0.24	756.38	4.81	3.40
XGJ	54.77	41	13	2.75	0.44	0.30	1676.57	2.66	3.08
XGL	70.62	28	15	2.82	0.47	0.30	1082.61	4.02	2.57
XGLJ	66.33	32	21	3.23	0.50	0.44	998.28	7.57	2.97
XLWTC	38.64	34	14	2.68	0.43	0.15	2024.01	1.78	4.69
XLWTY	9.66	41	13	3.62	0.58	0.22	511.93	1.99	7.46
XQC	70.83	35	16	2.23	0.35	0.22	2766.91	2.31	2.83
XZC	37.20	17	8	2.31	0.47	0.25	591.91	1.93	2.50
YGZ	43.44	20	11	2.52	0.47	0.56	1552.92	3.05	3.62
YLMDD	19.07	49	24	3.78	0.54	0.09	920.97	2.64	4.82
ZLDS	64.27	19	13	1.52	0.28	0.22	3068.77	1.44	1.52

Supplementary Table 4. Percentage of interactions of introduced honey bees and other native pollinators. This resulted in a clear dominance of honey bees in the bee-near plots regardless of the rapeseed cover.

	High rapeseed cover (n = 24)		Low rapeseed cover (n = 24)	
	Bee-near sites (n = 16)	Bee-far sites (n = 8)	Bee-near sites (n = 8)	Bee-far sites (n= 16)
Honey bees	67.73 ± 15.18	28.05 ± 14.02	64.09 ± 16.82	15.63 ± 13.65
Other pollinators	32.27 ± 15.18	71.95 ± 14.02	35.91 ± 16.82	84.37 ± 13.65

Supplementary Table 5 The fidelity of pollinator individuals. Differences in metrics were estimated by two-sided generalized linear mixed model (GLMM). Pollinator fidelity significantly increased in the bee-near plot, compared to the bee-bee-far plot (77.89% vs. 52.39%; GLMM; z_{314} = -2.46, P = 0.014, n = 318).

	Bee-near site			Bee-far site		
	No turnover	Turnover	Fidelity (%)	No turnover	Turnover	Fidelity (%)
Honey bees	49	5	90.74	23	4	85.19
Other bees	25	7	78.13	28	3	90.32
Flies	56	8	87.5	25	60	29.41
Butterflies	4	5	44.44	0	16	0

Supplementary Table 6. **Results of best (final) and full models of effects of MFCs and honeybees on plant–pollinator communities and network structure**. Differences in metrics were estimated by two-sided linear mixed models (LMMs) or generalized linear mixed models (GLMMs). Full models included main and interaction effects of the predictors 'MFC' and 'Distance'. Low MFC and Far sites were used as reference level of the factor treatments. Model selection was based on AICc, and ΔAICc indicates the difference between the best and next best model. Given are also AICc weights (AICcWt) showing model probabilities.

		Final models			Full models			
Model type	Predictor (n=48)	β	t	P	Predictor	*β*	*t*	*P*
LMM	rate of honey bees				MFCLow	-3.642	-0.623	0.537
	Best model, AICcWt = 0.312, $R^2_{LMM(m)}$ = 0.58, $R^2_{LMM(c)}$ = 0.761, Δ AICc = 3.51				**DistanceFar**	**-39.69**	**-6.787**	**2.62e-08**
	MFCLow	3.642	0.623	0.537	MFC:Distance	-0.761	-0.089	0.929
	DistanceFar	**-40.45**	**-6.484**	**2.62e-08**				
	MFC:Distance	0.761	0.089	0.93				
GLMM	the number of pollinator species (poisson (link = "log"))				**MFCLow**	**-0.193**	**-2.242**	**0.025**
	Best model, AICcWt = 0.312, $R^2_{LMM(m)}$ = 0.112, $R^2_{LMM(c)}$ = 0.581, Δ AICc = 4.57				DistanceFar	-0.127	-1.509	0.131
	MFC	**-0.193**	**-2.242**	**0.025**	**MFC:Distance**	**0.371**	**3.035**	**0.002**
	Distance	-0.127	-1.509	0.131				
	MFC:Distance	**0.371**	**3.035**	**0.002**				
GLMM	the number of pollinator visits (poisson (link = "log"))				**MFCLow**	**-0.200**	**-18.73**	**< 2e-16**
	Best model, AICcWt = 0.0.332, $R^2_{LMM(m)}$ = 0.96, $R^2_{LMM(c)}$ = 0.98, Δ AICc = 9.63				**DistanceFar**	**-0.275**	**-25.13**	**< 2e-16**
	MFCLow	**-0.200**	**-18.73**	**< 2e-16**	**MFC:Distance**	**-0.057**	**3.477**	**0.000507**
	DistanceFar	**-0.275**	**-25.13**	**< 2e-16**				
	MFC:Distance	**-0.057**	**3.477**	**0.000507**				
	DistanceFar:mfcLow	**0.132**	**2.21**	**0.027**				
LMM	Interaction evenness				MFCLow	0.01	0.415	0.68
	Best model, AICcWt = 0.91, $R^2_{LMM(m)}$ = 0.133, $R^2_{LMM(c)}$ = 0.533, Δ AICc = 5.92				DistanceFar	0.034	1.456	0.153

		Final models			Full models			
Model type	Predictor (n=48)	β	t	P	Predictor	*β*	*t*	*P*
	Distancef	**0.058**	**3.448**	**0.001**	MFC:Distance	0.037	1.083	0.285
LMM	Shannon diversity				MFCLow	-0.028	-0.166	0.869
	Best model, AICcWt = 0.675, $R^2_{LMM(m)}$ = 0.046, $R^2_{LMM(c)}$ = 0.697, Δ AICc = 3.65				DistanceFar	0.121	0.713	0.48
	Distance	**0.304**	**2.51**	**0.016**	MFC:Distance	0.327	1.314	0.196
LMM	Functional complementarity (log)				MFCLow	-0.15	-0.512	0.611
	Best model, AICcWt = 0.368, Adj. R^2 = 0.116, $F_{1,46}$ = 7.177, P = 0.01, Δ AICc = 1.09				DistanceFar	-0.37	-1.25	0.218
	Distance	**-0.521**	**-2.679**	**0.01**	MFC:Distance	-0.156	-0.374	0.71
LMM	Generality (log)				MFCLow	-0.046	-0.287	0.776
	Best model, AICcWt = 0.886, $R^2_{LMM(m)}$ = 0.302, $R^2_{LMM(c)}$ = 0.279, Δ AICc = 4.9				**DistanceFar**	**-0.46**	**-2.842**	**0.007**
	Distance	**-0.458**	**-4.226**	**3.74e-13**	MFC:Distance	0.018	0.08	0.936
LMM	Vulnerability				MFCLow	-0.249	-0.554	0.582
	Best model, AICcWt = 0.326, $R^2_{LMM(m)}$ = 0.432, $R^2_{LMM(c)}$ = 0.589, Δ AICc = 6.57				DistanceFar	0.544	1.212	0.232
	MFC	-0.249	-0.554	0.582	**MFC:Distance**	**1.951**	**2.98**	**0.005**
	Distance	0.544	1.212	0.232				
	MFC:Distance	**1.951**	**2.98**	**0.005**				
LMM	niche.overlap				MFCLow	-0.057	-0.994	0.326
	Best model, AICcWt = 0.958, $R^2_{LMM(m)}$ = 0.287, $R^2_{LMM(c)}$ = 0.364, Δ AICc = 6.76				**DistanceFar**	**-0.205**	**-3.569**	**0.000895**
	Distance	**-0.175**	**-4.41**	**6.23e-05**	MFC:Distance	0.076	0.924	0.361

Supplementary Table 7. **Results of best (final) and full models of the pollination function (fruit set and seed numbers) of plant communities**. Differences in metrics were estimated by two-sided generalized linear mixed models (GLMMs). Full models the predictors 'MFC (High and Low)', 'Distance (Near and Far)', 'Abundance (Rare and Common)', 'Reproductive system (partially self-compatible (SI) and self-compatible (SC))' and 'Native pollinator groups (Bumble bees (BB), Flies (F), Bumble bees and flies (BF))'. Low MFC, Far sites, SC, Rare and Bumble bees were used as reference level of the factor treatments. Model selection was based on AICc, and ΔAICc indicates the difference between the best and next best model. Given are also AICc weights (AICcWt) showing model probabilities.

	Final models				Full models			
Model type	Predictor	β	t	P	Predictor	β	t	P
GLMM	Fruit set (N_{obs} = 11749; $N_{plants:species}$ = 1299; $N_{species}$ = 21; N_{year} = 2)				MFCLow	-0.096	-1.132	0.258
	Best model, AICcWt = 0.355, $R^2_{LMM(m)}$ = 0.02, $R^2_{LMM(c)}$ = 0.453, Δ AICc = 0.82				**DistanceFar**	**-0.246**	**-3.527**	**0.00042**
	DistanceFar	**-0.247**	**-3.538**	**0.000403**	AdundanceRare	0.412	0.614	0.54
	MFCLow	-0.097	-1.139	0.255	ReproductivesystemSI	0.82	0.926	0.354
	Native pollinator BF	0.388	0.429	0.668	Native pollinator BF	0.40	0.45	0.653
	Native pollinator F	-0.594	-0.807	0.42	Native pollinator F	-0.847	-1.127	0.26
GLMM	Seed numbers (N_{obs} = 11749; $N_{plants:species}$ = 1299; $N_{species}$ = 21; N_{year} = 2)							
	Best model, AICcWt = 0.47, $R^2_{LMM(m)}$ = 0.003, $R^2_{LMM(c)}$ = 0.46, Δ AICc = 1.76				**MFCLow**	**-0.115**	**-18.61**	**< 2e-16**
				< 2e-16			**-**	
	DistanceFar	**-0.217**	**-39.663**		**DistanceFar**	**-0.217**	**39.663**	**< 2e-16**
	MFCLow	**-0.115**	**-18.61**	**< 2e-16**	AdundanceRare	-0.677	-1.24	0.215
	ReproductivesystemSI	0.222	0.302	0.762	ReproductivesystemSI	-1.35	-1.895	0.058
	Native pollinator BF	1.174	1.897	**0.058!**	Native pollinator BF	0.343	0.493	0.622
	Native pollinator F	-1.245	-1.753	**0.08!**	**Native pollinator F**	**1.248**	**0.634**	**0.039**

Supplementary Table 8. Pollination limitation of plant communities. Differences in pollination limitation were estimated by two-sided linear mixed model (LMM). Compared to the control treatment, flowers of supplemental pollination treatment produced 27.18% more seed numbers per fruit across 12 flowering plant species (LMM; t = -9.466, P = 0.000013, n = 1257).

Species	Treatments	N	Seed number (Mean ± SD)
Gentiana aristata	Supplementary pollination	65	86.23 ± 31.04
	Control	63	65.53 ± 35.35
Euphrasia regelii	Supplementary pollination	32	33.21 ± 10.18
	Control	37	23.86 ± 7.55
Saussurea nigrescens	Supplementary pollination	76	10.21 ± 5.16
	Control	75	10.09 ± 7.03
Oxytropis kansuensis	Supplementary pollination	68	7.48 ± 2.71
	Control	74	6.67 ± 1.89
Saussurea superba	Supplementary pollination	74	83.56 ± 29.50
	Control	77	76.80 ± 35.73
Oxytropis ochrocephala	Supplementary pollination	36	7.75 ± 1.71
	Control	34	7.32 ± 1.99
Gentiana aperta var. *aperta*	Supplementary pollination	43	27.44 ± 20.87
	Control	88	17.51 ± 18.63
Delphinium caeruleum	Supplementary pollination	35	106.12 ± 24.25
	Control	33	95.68 ± 31.83
Ranunculus membranaceus	Supplementary pollination	56	65.51 ± 28.56
	Control	61	25.65 ± 23.72
Oxytropis qinghaiensis	Supplementary pollination	35	7.25 ± 1.78
	Control	37	6.75 ± 2.01
Parnassia trinervis	Supplementary pollination	40	117.28 ± 70.50
	Control	39	109.35 ± 59.89
Allium cyaneum	Supplementary pollination	40	4.57 ± 1.59
	Control	39	3.43 ± 1.88

Supplementary Table 9. **Pollination effectiveness of introduced honey bee and resident pollinators (bumble bees and flies).**

	n	Fruit sets	The ratio of seed to ovule
Honey bees	32	85.45%	0.67 ± 0.43
Bumble bees	55	100%	0.81 ± 0.36
Flies	115	63.48%	0.35 ± 0.41

Supplementary Table 10. Pollinator visits of 21 wild plant species. Most of flowering plant species were visited by flies and/or bumble bees and were self-compatible in the alpine grasslands. We also identified species as dominant (q = 2; Simpson diversity), common (q =1; Shannon diversity) or rare (q = 0) species based on Hill numbers.

Names	Abundance	Reproductive system	Native pollinators	Pollinator turnover	Introduced honey bees (%)	Other bees (%)	Butterflies and moth (%)	Flies (%)	Other insects (%)	Seed number change
Dracocephalum heterophyllum	rare	self-compatible	Bumble bees	Honey bees	47.27	52.51	0.22	0.00	0.00	not change
Euphrasia regelii	rare	self-compatible	Bumble bees and flies	Honey bees	58.21	15.97	0.79	25.03	0.00	increased
Aster hispidus	common	self-compatible	Bumble bees and flies	Honey bees	10.52	5.45	2.57	80.44	1.02	increased
Microula sikkimensis	rare	self-compatible	Bumble bees and flies	Honey bees	88.78	2.48	2.31	6.43	0.00	not change
Salvia roborowskii	rare	self-compatible	Bumble bees	Honey bees	34.72	64.17	1.11	0.00	0.00	decreased
Hypochaeris ciliata	rare	self-compatible	Flies	Honey bees	48.86	7.05	6.14	34.55	3.41	decreased
Gentiana aristata	common	self-compatible	Flies	Flies	0.00	5.13	19.87	75.00	0.00	decreased
Pedicularis kansuensis	common	self-compatible	Bumble bees	Honey bees	31.62	67.79	0.23	0.36	0.00	increased
Oxytropis ochrocephala	common	partially self-compatible	Bumble bees	Honey bees	52.17	47.21	0.53	0.03	0.05	not change
Gentiana straminea	rare	self-compatible	Bumble bees	Honey bees	63.55	29.35	0.00	6.77	0.32	increased
Picris hieracioides	rare	self-compatible	Flies	Honey bees	13.27	2.65	3.54	78.76	1.77	decreased
Melilotus officinalis	rare	self-compatible	Bumble bees	Honey bees	98.89	1.11	0.00	0.00	0.00	decreased

Names	Abundance	Reproductive system	Native pollinators	Pollinator turnover	Introduced honey bees (%)	Other bees (%)	Butterflies and moth (%)	Flies (%)	Other insects (%)	Seed number change
Saussurea japonica	rare	self-compatible	Flies	Honey bees	4.26	0.00	5.67	90.07	0.00	increased
Carum carvi	common	partially self-compatible	Flies	Honey bees	22.35	3.99	0.43	68.85	4.39	increased
Allium sikkimense	rare	self-compatible	Bumble bees(rare)	Honey bees	40.00	0.00	28.00	32.00	0.00	not change
Ligularia sagitta	rare	partially self-compatible	Flies	Honey bees	71.52	3.17	2.27	22.72	0.32	decreased
Delphinium caeruleum	rare	self-compatible	Bumble bees(rare)	Honey bees	35.71	42.86	21.43	0.00	0.00	increased
Elsholtzia densa	rare	self-compatible	Bumble bees and flies	Honey bees	54.64	27.61	0.05	17.65	0.05	not change
Veronica polita	rare	partially self-compatible	Flies	Honey bees	76.92	0.00	0.00	23.08	0.00	decreased
Geranium sibiricum	rare	self-compatible	Bumble bees and flies	Honey bees	32.10	49.23	0.00	18.67	0.00	increased
Cirsium arvense	common	self-compatible	Flies	Honey bees	61.92	2.95	3.37	31.63	0.13	increased

Supplementary Table 11. The effects of honey bees on the seed numbers of 21 plant species. Differences in seed numbers were estimated by two-sided generalized linear mixed models (GLMMs). The predictor is 'Distance (Near and Far)', Far sites were used as reference level of the factor treatments. GLMMs with poisson distributions. Plant individuals and the year were assigned as random effects.

	Honey bees (bee-far plots)				
species	N	Estimate	SE	Z	P
Dracocephalum heterophyllum	1014	-0.01755	0.04446	-0.395	0.693
Gentiana aristata	210	0.30829	0.02345	13.15	<2e-16
Melilotus officinalis	331	0.23892	0.08925	2.677	0.00743
Saussurea japonica	195	-2.0665	0.2252	-9.176	<2e-16
Carum carvi	398	-0.22644	0.10164	-2.228	0.0259
Allium sikkimense	477	-0.04261	0.0553	-0.771	0.441
Pedicularis kansuensis	1119	-0.16356	0.02269	-7.21	5.61e-13
Aster hispidus	377	-0.28946	0.02215	-13.07	<2e-16
Oxytropis ochrocephala	561	-0.05166	0.05555	-0.93	0.352
Ligularia sagitta	448	0.50161	0.02954	16.98	<2e-16
Delphinium caeruleum	66	-0.68967	0.13564	-5.085	3.68e-07
Hypochaeris ciliata	502	0.32634	0.01251	26.08	<2e-16
Gentiana straminea	664	-0.599411	0.009686	-61.89	<2e-16
Elsholtzia densa	1108	-0.01035	0.04848	-0.213	0.831
Picris hieracioides	278	0.11622	0.02734	4.252	2.12e-05
Veronica polita	354	0.5314	0.07685	6.915	4.68e-12
Geranium sibiricum	959	-0.10434	0.03281	-3.18	0.00147
Euphrasia regelii	1218	-0.05706	0.01547	-3.687	0.000227
Microula sikkimensis	164	0.0828	0.1278	0.648	0.517
Cirsium arvense	691	-0.26277	0.01566	-16.78	<2e-16
Salvia roborowskii	615	0.19212	0.04648	4.134	2.78e-05

Supplementary Table 12. **Key experimental studies demonstrating the effects of managed introduced species on biodiversity and ecosystem functioning.** Previous studies found that beekeeping activities poisoned the structure and function of pollination networks. However, our results demonstrated that the spillover of introduced honey bees from mass-flowering crops into natural habitats did not harm populations and richness of wild pollinators. Furthermore, honey bee spillover improved plant communities' pollination function.

Location	System (introduced species)	Methods	Key findings	Effects on diversity and ecosystem functioning	Limitations	References
Seychelles	Exotic plants	The impacts of Ecosystem (removed exotic plants) restoration on pollination network structure and function; reproductive success of 10 plant species; 8 sites; one year	Ecosystem restoration strengthens pollination network resilience and function. Ecosystem restoration resulted in increase in pollinator species, flower visits, interaction diversity, fruit production of native plants.	Exotic plants have negative effect on pollinator diversity, the structure of pollination networks, fruit set of native plants	Not consider the introduced honey bees	Kaiser-Bunbury, C.N., Mougal, J., Whittington, A.E., et al. (2017). Ecosystem restoration strengthens pollination network resilience and function. Nature, 542, 223-227.
Canary Islands, Spain	Introduction honey bees	Compare the effects of pre- and post-establishment stages of beehives on the pollination network structure and plant reproductive success; fruit set and seeds of five plant species; 1 site; three years	Beekeeping reduced the diversity of wild pollinators and interaction links and impaired pollination services of plant species highly visited by honey bees.	Introduction honeybees have negative effect on pollinator diversity, the structure of pollination networks, fruit set of native plants	Only considered natural vegetable and five plant species for functional response; lack of replicates (n=2)	Valido, A., Rodriguez-Rodriguez, M.C. & Jordano, P. (2019). Honeybees disrupt the structure and functionality of plant-pollinator networks. Sci Rep, 9, 4711.
Cycladic islands, central Aegean Sea, Greece.	Introduction honey bees	The effects of honey bee density on wild bee diversity and the structure of pollination networks; 41 study sites in 13 islands; three years	Increasing honey bee visitation rate had negative effect on wild bee richness and abundance, increased competition for flowering resources and influenced the structure of pollination networks indirectly through an effect on the number of wild bees in the communities	Introduction honeybees have negative effect on pollinator diversity, the structure of pollination networks	only included wild bees; No functional response	Lázaro A, Müller A, Ebmer AW, Dathe HH, Scheuchl E, Schwarz M, Risch S, Pauly A, Devalez J, Tscheulin T, Gómez-Martínez C, Papas E, Pickering J, Waser NM, Petanidou T. 2021. Impacts of beekeeping on wild bee diversity and pollination networks in the Aegean Archipelago. Ecography 44: 1353-1365.

Location	System (introduced species)	Methods	Key findings	Effects on diversity and ecosystem functioning	Limitations	References
the eastern Tibetan Plateau, Sichuan Province, China	Introduction honeybees	The impacts of the density of honey bees affects the abundance of 10 nectareous plants and the species richness and abundance of native bumble bees; 3 sites; one year	Introduced honey bees increase host plant abundance but decrease native bumble bee species richness and abundance	Introduction honeybees have negative effect on pollinator diversity and positive on fruit set of native plants	Only included bumblebees; Not consider the impact of introduced honeybees on the plant-pollinator interaction network; lack of replicates (n=3)	Su RJ, Dai WF, Yang YL, Wang XL, Gao R, He MY, Zhao C, Mu JP. 2022. Introduced honey bees increase host plant abundance but decrease native bumble bee species richness and abundance. Ecosphere 13: e4085.
SW Spain	Mass-flowering crops (orange groves) and introduction honeybees	The effects of honey bee spillover after orange blooming on pollination network structure and plant reproductive success; reproductive success of 2 plant species; 17 sites (nine high cover and eight no/low cover of crops); 64 pollination networks; two years	Honeybee spillover increased apparent competition between honeybees and wild pollinators, and modified plant-pollinator network structure, and decreased seed set of the most abundant plant species.	Honeybee spillover have negatives effect on pollinator diversity, the structure of pollination networks, fruit set of native plants	Only included bees and hoverflies; Only collected two plant species for functional response	Magrach, A., González-Varo, J.P., et al., (2017). Honeybee spillover reshuffles pollinator diets and affects plant reproductive success. Nat Ecol Evol, 1, 1299-1307.
The NE of Qinghai-Tibet Plateau, China	Mass-flowering crops (Brassica rapa var. oleifera) and introduced honeybees	The effects of beekeeping on pollination network structure and the reproductive performance of wild plant species; fruit set and seeds of 21 plant species; 48 sites (24 high cover and 24 no/low cover of crops); two years	Honey bee spillover have neutral effect on pollinator communities; Honeybee spillover improve pollination services	The positive impacts of honeybee spillover on the alpine pollination ecosystems		Our study

Supplementary Table 13. Spatial autocorrelation. There was no correlation between the spatial distance among 48 sites (Mean ± SD; 96.14 ± 78.04 km) and the composition of plant or pollinator communities or other network metrics (Mantel statistic; all $P > 0.05$, $n = 48$).

Descriptor	Mantel r	*P*
Plant species	-0.04	0.62
Pollinator species	0.117	0.096
Number of visits	0.065	0.209
Interaction diversity	-0.036	0.675
Interaction evenness	-0.015	0.536
Floral abundance	0.163	0.054
The density of honey bee spillover	-0.034	0.703
Niche overlap	0.018	0.373
Functional complementarity	0.091	0.149
Generality	-0.08	0.764
Vulnerability	-0.145	0.989

Supplementary Table 14. Plant list. The flowering plant species are mainly Ranunculaceae, Fabaceae, Asteraceae, and Gentianaceae. Species such as *Ranunculus tanguticus, Oxytropis ochrocephala, Pedicularis kansuensis, Cirsium lanatum*, and *Gentiana straminea* are abundant from June to September.

Aconitum gymnandrum	*Dracocephalum heterophyllum*	*Klasea centauroides*	*Oxytropis microphylla*	*Saussurea japonica*
Adenophora stricta	*Dracocephalum ruyschiana*	*Lactuca tatarica*	*Oxytropis ochrocephala*	*Saussurea subulisquama*
Ajania tenuifolia	*Elsholtzia densa*	*Lamium amplexicaule*	*Oxytropis qinghaiensis*	*Saussurea superba*
Allium sikkimense	*Erigeron acris*	*Lappula myosotis*	*Parnassia trinervis*	*Scorzonera austriaca*
Allium thunbergii	*Erodium stephanianum*	*Lepidium latifolium*	*Pedicularis flava*	*Senecio thianschanicus*
Anaphalis sinica	*Euphrasia regelii*	*Lepyrodiclis holosteoides*	*Pedicularis kansuensis*	*Solanum nigrum*
Anemone rivularis	*Galeopsis bifida*	*Ligularia sagitta*	*Pedicularis longiflora*	*Sonchus uliginosus*
Aster farreri	*Galium verum*	*Ligularia virgaurea*	*Pedicularis lyrata*	*Sphaerophysa salsula*
Aster hispidus	*Gentiana aristata*	*Ligusticum sinense*	*Pedicularis qinghaiensis*	*Stellera chamaejasme*
Astragalus laxmannii	*Gentiana macrophylla*	*Linum usitatissimum*	*Pedicularis siphonantha*	*Swertia bimaculata*
Bupleurum chinense	*Gentiana parvula*	*Lycium chinense*	*Phedimus aizoon*	*Tanacetum tatsienense*
Capsella bursa pastoris	*Gentiana straminea*	*Medicago archiducis nicolai*	*Picris hieracioides*	*Taraxacum mongolicum*
Caragana sinica	*Gentiana syringea*	*Medicago falcata*	*Polygonum viviparum*	*Thalictrum aquilegiifolium*
Carduus nutans	*Gentianopsis barbata*	*Medicago sativa*	*Potentilla anserina*	*Thermopsis lanceolata*
Carum carvi	*Gentianopsis paludosa*	*Melilotus officinalis*	*Potentilla bifurca*	*Tibetia himalaica*
Cirsium arvense	*Geranium sibiricum*	*Microula sikkimensis*	*Potentilla fruticosa*	*Veronica polita*
Cirsium japonicum	*Geranium wilfordii*	*Morina kokonorica*	*Potentilla glabra*	
Clematis tangutica	*Glycyrrhiza uralensis*	*Onopordum acanthium*	*Potentilla multicaulis*	
Comastoma pulmonarium	*Halenia elliptica*	*Ophioglossum vulgatum*	*Ranunculus membranaceus*	
Convolvulus arvensis	*Hemerocallis citrina*	*Oxytropis caerulea*	*Ranunculus tanguticus*	
Delphinium caeruleum	*Hypochaeris ciliata*	*Oxytropis fetissovii*	*Raphanus sativus*	
Descurainia sophia	*Ixeris polycephala*	*Oxytropis kansuensis*	*Salvia roborowskii*	

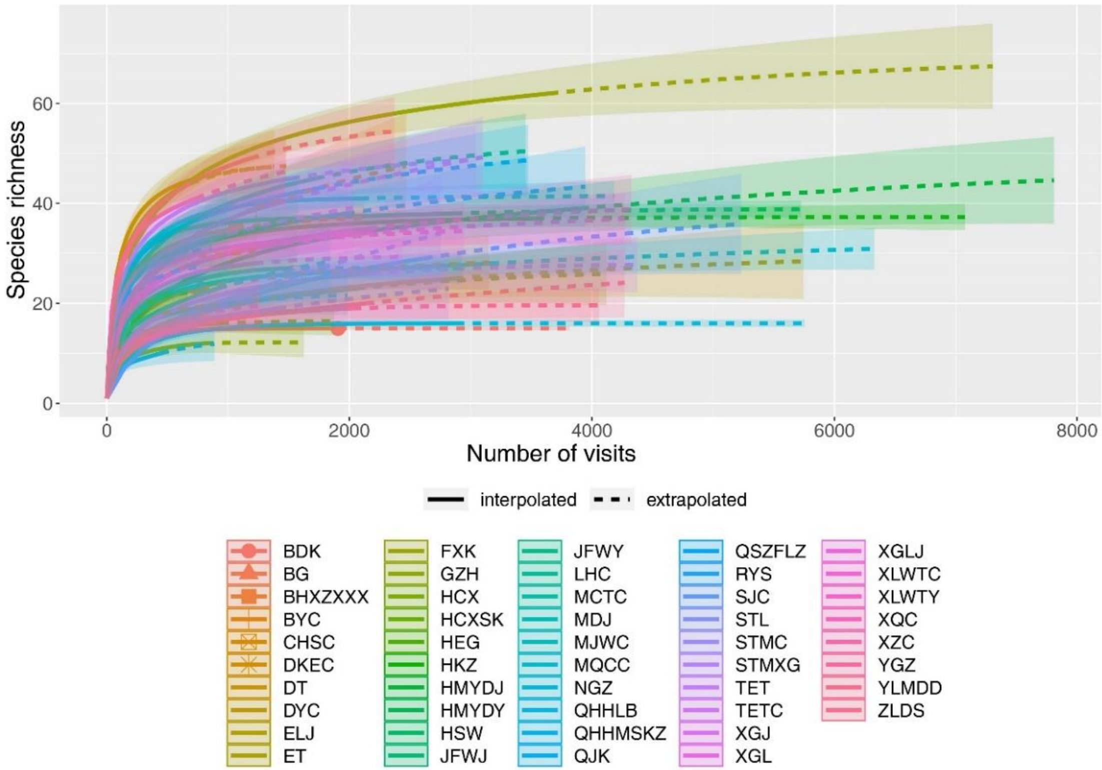
Supplementary Table 15. Pollinator list. Pollinator groups include introduced honey bees, native bees, butterflies and moths, beetles, and flies.

Carabidae sp1	*Empis sp1*	*Platycheirus sp2*	Tachinidae sp3	*Bombus supremus*	*Everes argiades*
Cerambycidae sp1	Muscidae sp1	*Pseudovolucella sp1*	Tachinidae sp4	*Colletes sp1*	*Satyrium sp1*
Chrysomelidae sp1	Muscidae sp2	*Scaeva pyrastri*	Tachinidae sp5	*Myrmica sp1*	*Satyrium sp2*
Chrysomelidae sp2	Muscidae sp3	*Sphaerophoria sp1*	Tachinidae sp6	*Lasioglossum sp1*	*Satyrium sp3*
Chrysomelidae sp3	Muscidae sp4	*Sphaerophoria viridaenea*	Tephritidae sp1	*Lasioglossum sp2*	*Zizina otis*
Coccinella septempunctata	Muscidae sp5	Syrphidae sp1	Tephritidae sp2	*Lasioglossum sp3*	*Apamea sp1*
Curculionidae sp1	Muscidae sp6	Syrphidae sp2	*Nysius sp*	Ichneumonidae sp1	*Apamea sp2*
Elateridae sp	Sarcophagidae sp1	Syrphidae sp3	*Miridae sp*	Ichneumonidae sp2	*Apamea sp3*
Oedemeridae sp	Sarcophagidae sp2	Syrphidae sp4	*Holcostethus sp*	Ichneumonidae sp3	*Nolidae sp1*
Pyrochroidae sp	Sarcophagidae sp3	Syrphidae sp5	Pentatomidae sp1	Ichneumonidae sp4	*Clossiana gong*
Rhomborrhina splendida	Sarcophagidae sp4	Syrphidae sp6	Pentatomidae sp2	Ichneumonidae sp5	*Inachis io*
Scarabaeidae sp1	Sarcophagidae sp5	*Syrphus ribesii*	Pentatomidae sp3	Ichneumonidae sp6	*Issoria eugenia*
Scarabaeidae sp2	*Sciara sp1*	*Volucella plumatoides*	Rhopalidae sp1	*Megachile sp1*	*Speyeria aglaja*
Bombylius major	*Cheilosia sp1*	*Archytas sp1*	Rhopalidae sp2	*Nesoselandria sp1*	*Vanessa cardui*
Bombylius sp1	*Eristalis sp1*	*Eurithia sp1*	*Andrena*	*Tenthredo mesomela*	*Anthocharis sp1*
Bombylius sp2	*Eristalis tenax*	*Eurithia sp1*	*Megandrena*	*Tenthredo sp1*	*Aporia hippia*
Chrysomyia sp1	*Eupeodes corollae*	*Eurithia sp2*	Apidae sp1	*Tenthredo sp2*	*Colias fieldii*
Chrysomyia sp2	*Leucozona lucorum*	*Gymnosoma sp1*	Apidae sp2	*Edulicodes sp1*	*Colias mantium*
Lucilia sp1	*Leucozona sp1*	*Ocyptera brassicaria*	*Apis mellifera*	*Spoladea sp2*	*Colias sp1*
Lucilia sp2	*Leucozona sp2*	*Pales sp1*	*Bombus sp1*	*Ochlodes sp1*	*Colias sp2*
Conops flavipes	*Melangyna lasiophthalma*	*Sturmia sp1*	*Bombus sp2*	*Albulina orbitulus*	*Pieris rapae*
Conops sp1	*Myathropa florae*	*Tachina fera*	*Bombus asiaticus*	*Albulina sp1*	*Pieris sp1*
Conops sp2	*Pipiza sp1*	Tachinidae sp1	*Bombus kashmirensis*	*Celastrina argiola*	*Pontia daplidice*
Conops sp3	*Platycheirus sp1*	Tachinidae sp2	*Bombus ladakhensis*	*Cupido minimus*	*Scythris sp1*
Scythris sp2	*Scythris sp3*	*Scythris sp4*	Xyloryctidae sp1		

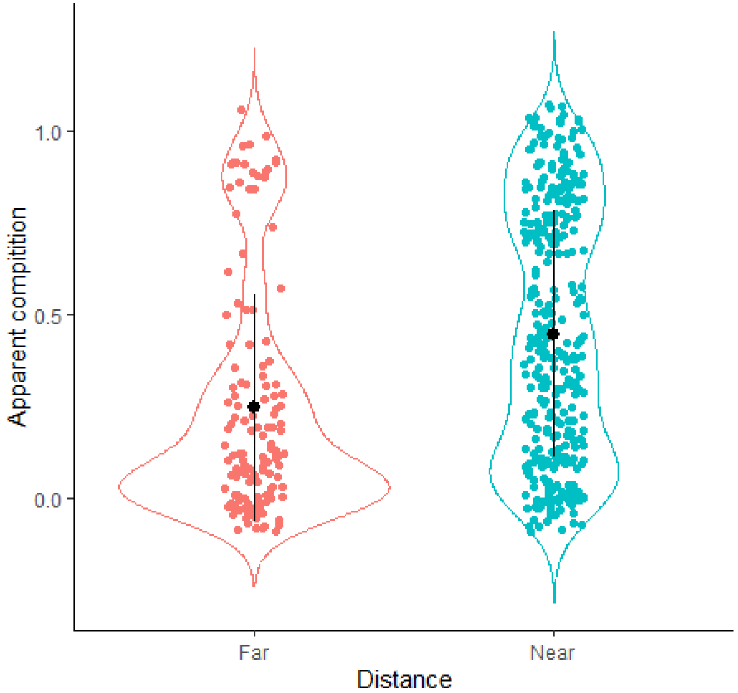
Supplementary Table 16. Network metrics used in this study.

Network parameters	Definition and purpose	References
Interaction diversity	Shannon's diversity of interactions: the α-diversity Shannon index calculated for the links existing within a network; Interaction diversity is the weighted interaction diversity across a network, best expressed as the exponent of Shannon Entropy *H*2 across all links. As with standard diversity metrics, interaction diversity is a composite metric that contains ecologically important information on the richness of interactions and the homogeneity of relative interaction frequencies (interaction evenness)	Dormann, C.F., Fründ, J., Blüthgen, N., & Gruber, B. Indices, Graphs and Null Models: Analyzing Bipartite Ecological Networks. *The Open Ecology Journal, 2*, 7-24 (2009).
Interaction evenness	Shannon's evenness for the web entries. Interaction evenness describes the evenness of the distribution of interactions in a network, with high values reflecting a more uniform spread of interactions among the species in the community. The metrics interaction diversity and interaction evenness of the networks characterize aspects of complexity in diversity and distribution of interactions between plants and pollinators	Blüthgen N, Fründ J, Vázquez DP, Menzel F. What do interaction network metrics tell us about specialization and biological traits? *Ecology*. 89:3387-3399 (2012)
Functional complementarity of pollinators	Functional complementarity of a pollinator species measures the niche complementarity of a pollinator species and is computed as the total branch length of a "functional dendrogram" based on qualitative differences in interactions between one level with another. Functional complementary suggests that a higher diversity of pollinators contributes to an increased pollination success of the plants.	Blüthgen N, Klein AM. Functional complementarity and specialisation: The role of biodiversity in plant-pollinator interactions. *Basic Appl Ecol* **12**, 282-291 (2011).
Generality of pollinators	(Weighted) mean effective number of plant species per pollinator species, weighted by their marginal totals (row sums); increased generality indicates an expansion of the range of species attacked, an increase in the abundance of generalist species or both.	Bersier LF, Banašek-Richter C, Cattin MF. Quantitative descriptors of food-web matrices. *Ecology* **83**, 2394-2407 (2002).
Niche overlap of plants	Niche overlap of plant species is the mean similarity in interaction patterns between plant species, calculated by default as Horn's index.	Ollerton J, Stott A, Allnutt E, Shove S, Taylor C, Lamborn E. Pollination niche overlap between a parasitic plant and its host. *Oecologia* **151**, 473-485 (2007).
Vulnerability of plants	(Weighted) mean effective number of pollinator species per plant species, weighted by their marginal totals (row sums); Increased vulnerability indicates increasing dependency of the insect community on fewer plant species.	Bersier LF, Banašek-Richter C, Cattin MF. Quantitative descriptors of food-web matrices. *Ecology* **83**, 2394-2407 (2002).
Interaction turnover	beta_OS, the dissimilarity (component) explained by "rewiring" among shared species; rewiring link dissimilarity ("beta_OS" or simply "OS") by focusing on the sub-web containing only species observed in both webs (i.e. excluding links with species unique to one of the webs)	Poisot, T., E. Canard, D. Mouillot, N. Mouquet, D. Gravel, and F. Jordan. The dissimilarity of species interaction networks. Ecology Letters 15, 1353–1361 (2012)

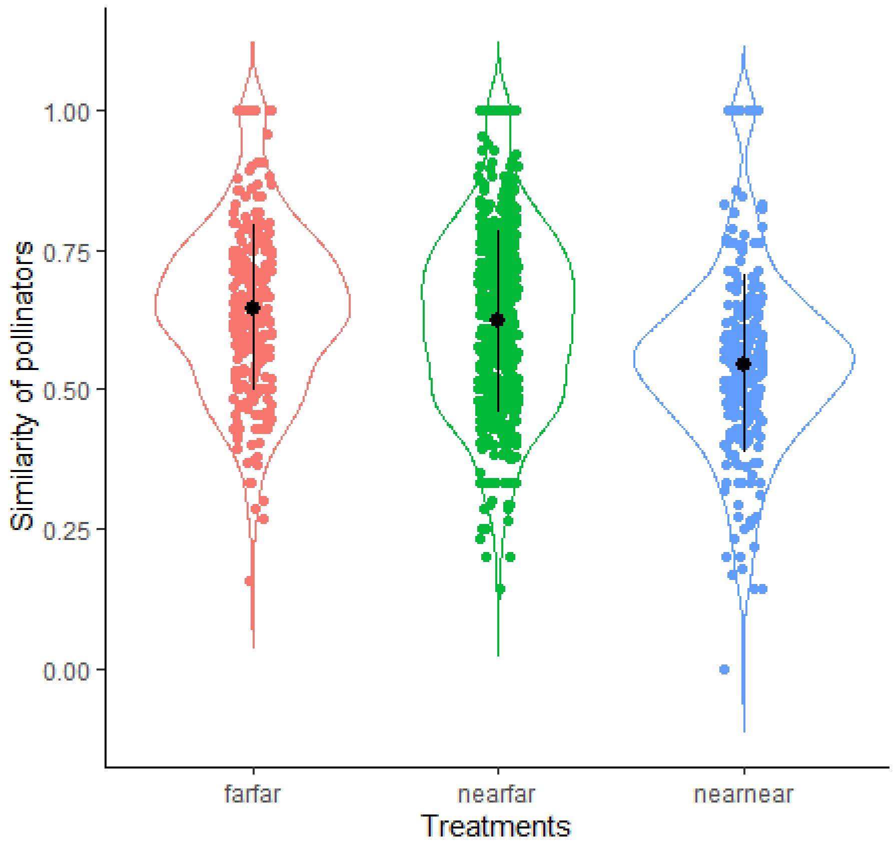
Supplementary Figures



Supplementary Fig. 1. Sampling completeness of plant-pollinator interactions at 48 plant-pollinator communities. Our study captured more than 83% of the richness of the pollinator species and about 73% of the richness of plant-pollinator interactions.

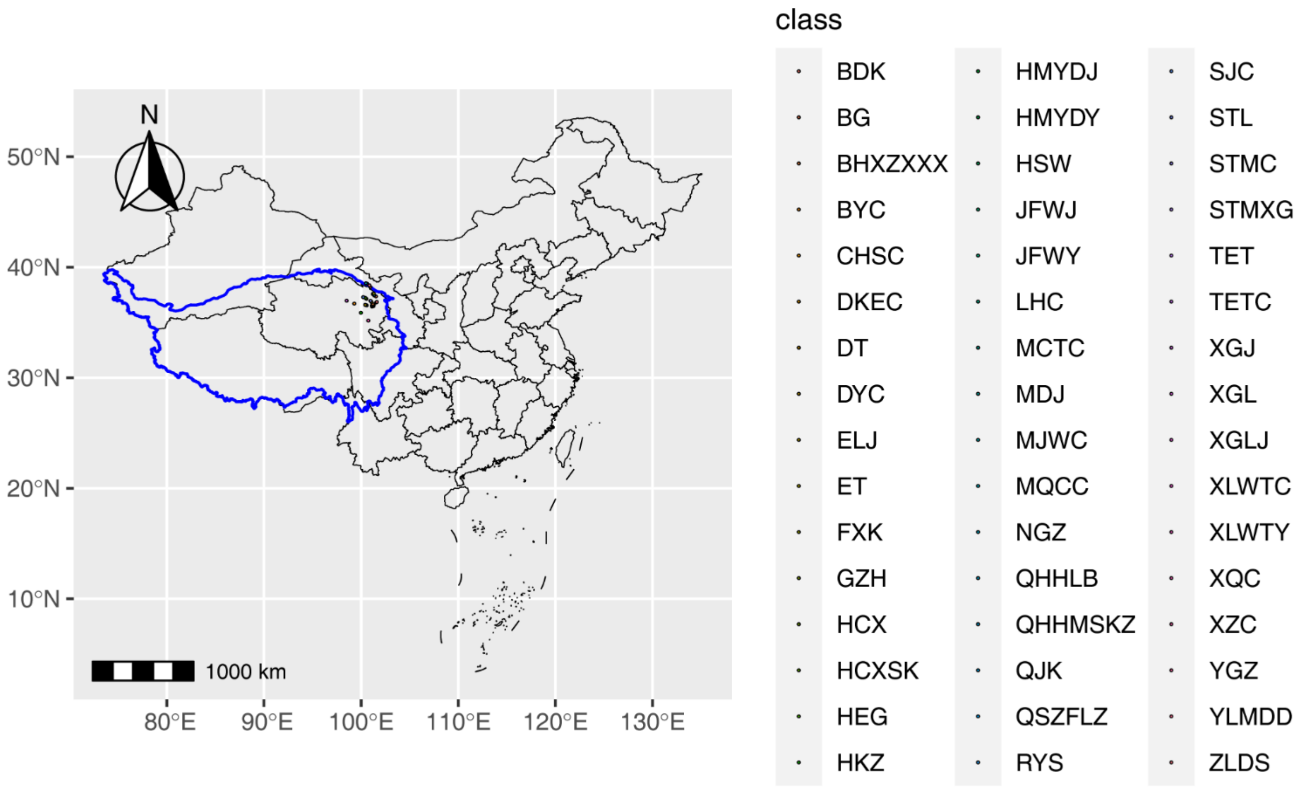


Supplementary Fig. 2. Honey bee spillover caused the apparent competition (mean ± SD) between honey bees and the other pollinator species. Differences in metrics were estimated by two-sided linear mixed model (LMM). Compared to the bee-far plots (n = 137), there was an increased apparent competition (LMM: t= 6.317, P < 0.001) between honey bees and other pollinators in the bee-near plots (n = 347). Data represent the subset of pairwise calculations between honey bees and other pollinators that showed values > 0. Source data are provided as a Source Data file.

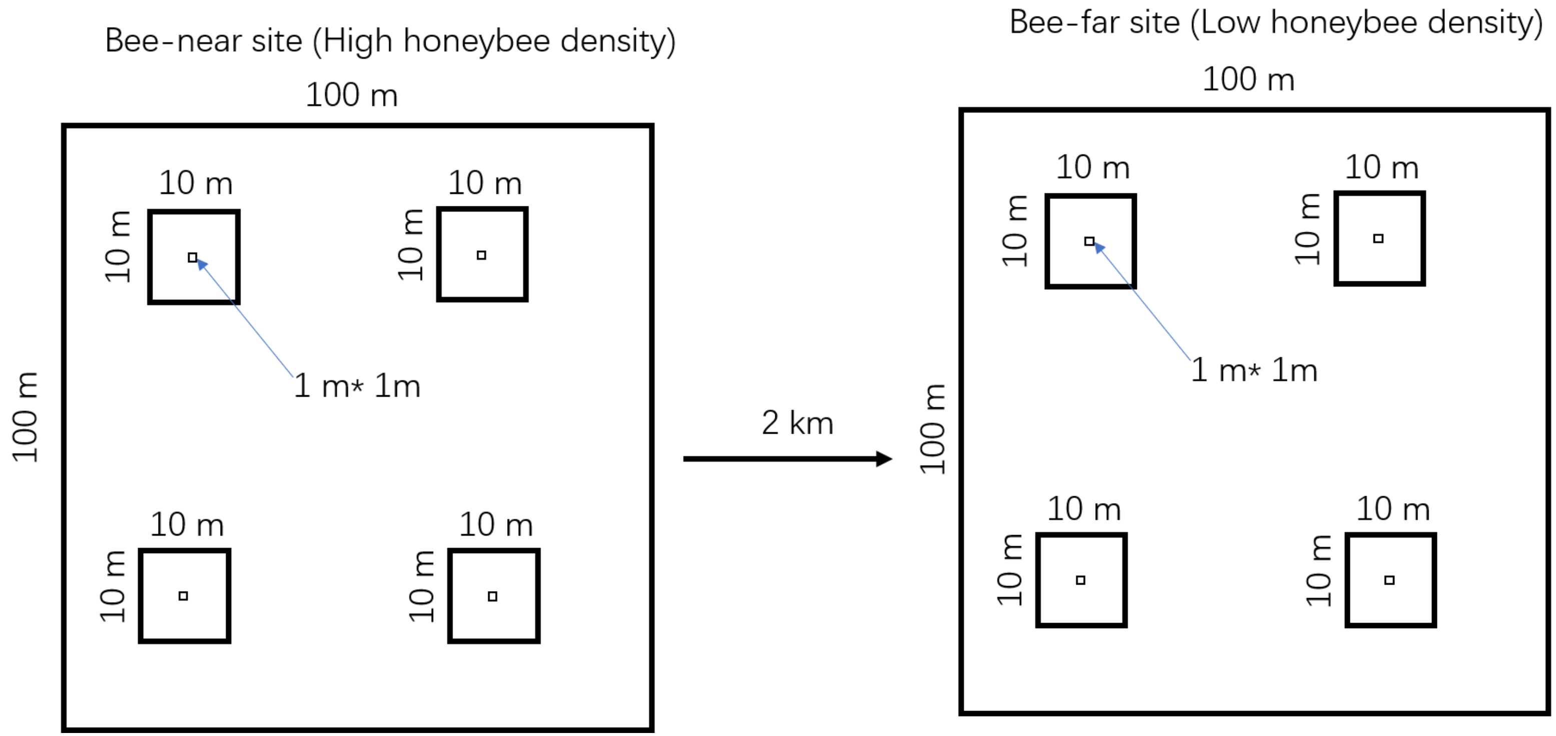


Supplementary Fig. 3. Interaction turnover (beta OS; mean ± SD) among three treatments (within bee-far sites (n = 276), within bee-near sites (n = 276), and between bee-far and bee-near sites (n = 576)). Differences in metrics were estimated by two-sided linear mixed model (LMM). Compared to within the bee-far plots, there was a decreased interaction turnover within bee-near sites (LMM: t = -3.963, P = 0.00017). Source data are provided as a Source Data file.

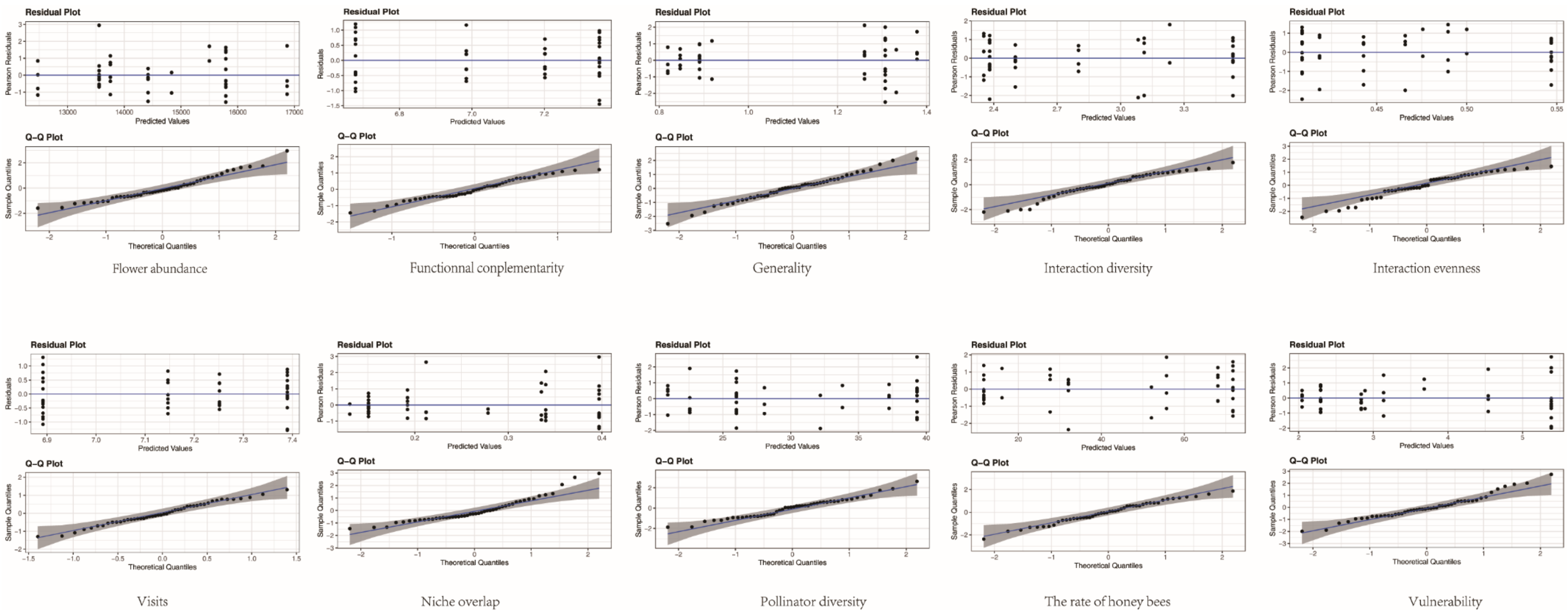
Supplementary Fig. 4. Vegetation of alpine grasslands. All study sites had typical alpine grassland vegetation and comparable climate in the northeastern of the Tibetan Plateau. The Tibetan grassland agroecosystems are characterized by relatively small fields and neighboring large (semi-)natural habitats. All landscape photos © Lin-Lin Wang.



Supplementary Fig. 5. Sampling sites at Tibetan alpine grasslands. The selection criteria for the study sites were an altitude between 2700 and 3400 m above sea level, a size of more than 1 ha, similar native plant communities, and accessibility. The sample map was made using R 4.2.2. The base map was obtained from the Alibaba Cloud Data Visualization platform (http://datav.aliyun.com/portal/school/atlas/area_selector).



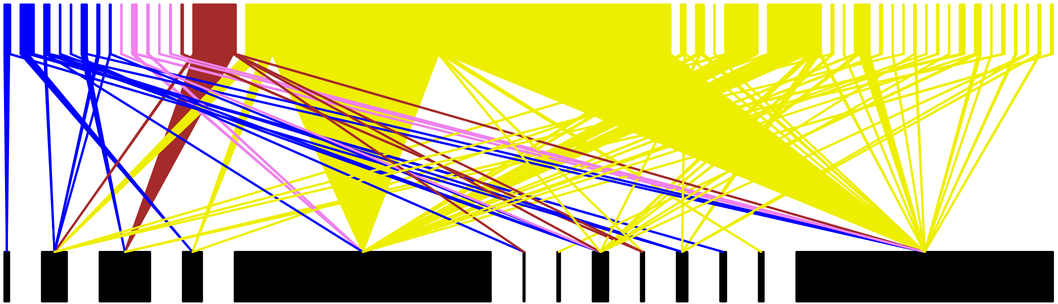
S**upplementary Fig. 6. Schematic diagram of plots for following the movements of the pollinators.** Pollinator fidelity significantly increased in the bee-near plot, compared to the bee-bee-far plot (77.89% vs. 52.39%; z = -2.46, P = 0.014), indicating greater pollinator fidelity in bee-near site.



Supplementary Fig. 7. Residual plots and QQ plots. Metrics include flower abundance, functional complementarity, interaction diversity, interaction evenness, generality, visits, niche overlap, pollinator diversity, the rate of honey bees, vulnerability.

Supplementary Fig. 8. The full size of 48 networks. The networks in 24 bee-near sites (From top to bottom, they were HCXSK, JFWJ, MCTC, QJK, TETC, MQCC, HKZ, XGJ, DYC, CHSC, ZLDS, XGLJ, XGL, XQC, ELJ, STL, TET, HCX, STMC, HMYDJ, GZH, QHHLB, QHHMSKZ, SJC) and 24 bee-far sites (From top to bottom, they were BYC, DKEC, QSZFLZ, HSW, HMYDY, STMXG, DT, JFWY, MJWC, HEG, XLWTY, FXK, YLMDD, ET, LHC, BG, BHXZXXX, RYS, MDJ, XZC, XLWTC, BDK, NGZ, YGZ).

BYC



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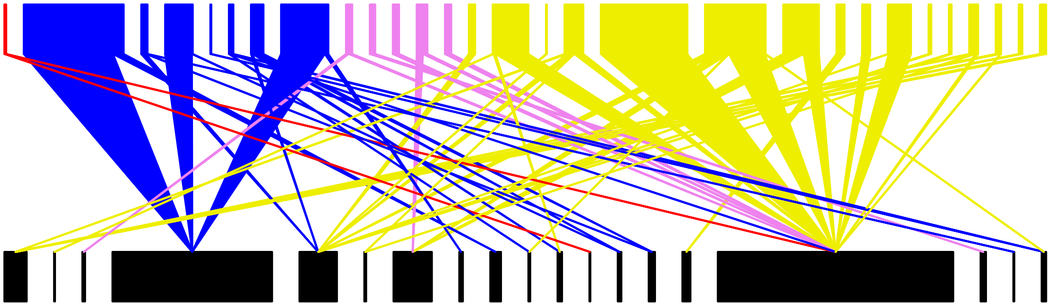
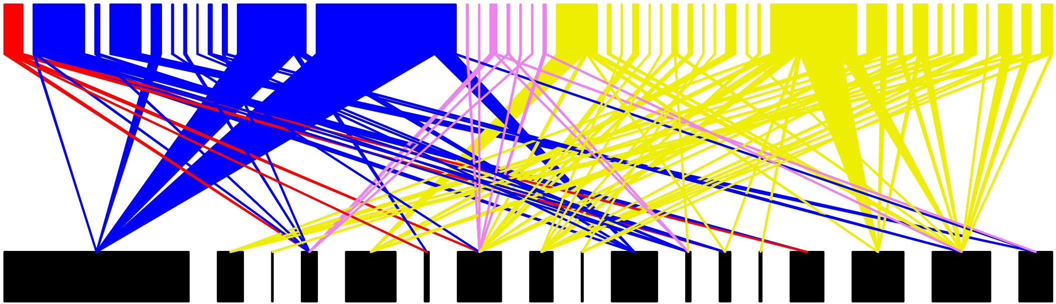
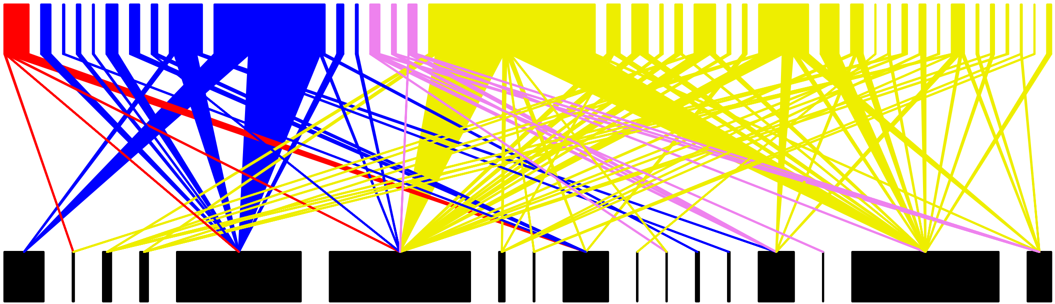


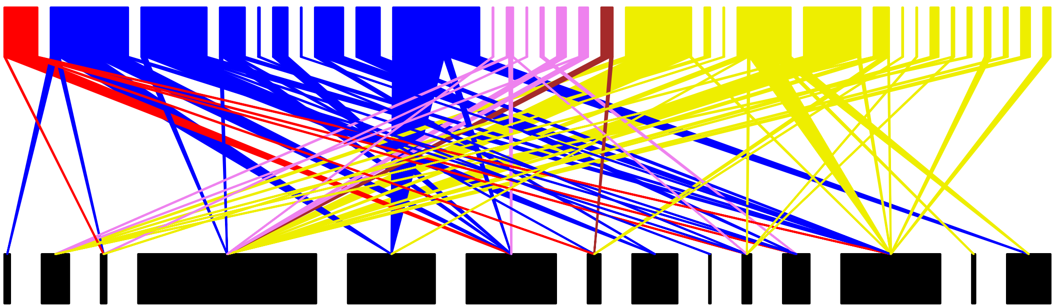
QSZFLZ

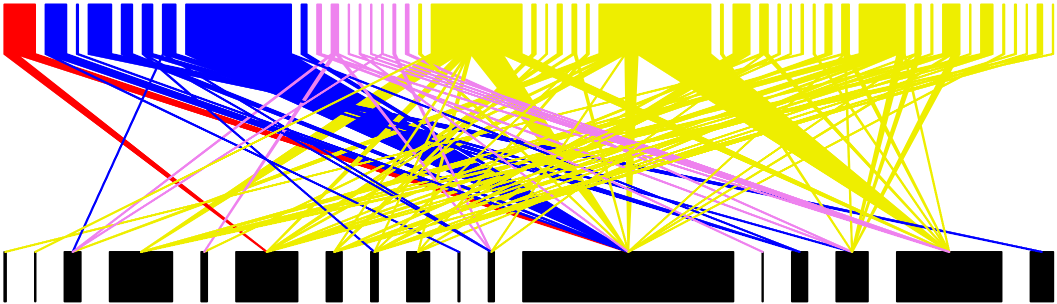


HSW



HMYDY





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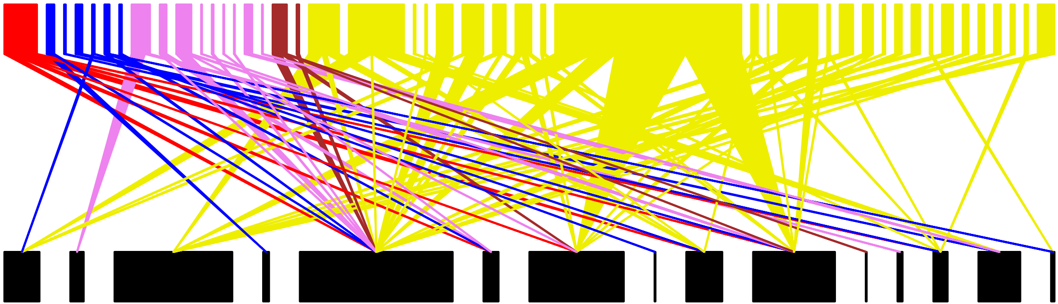
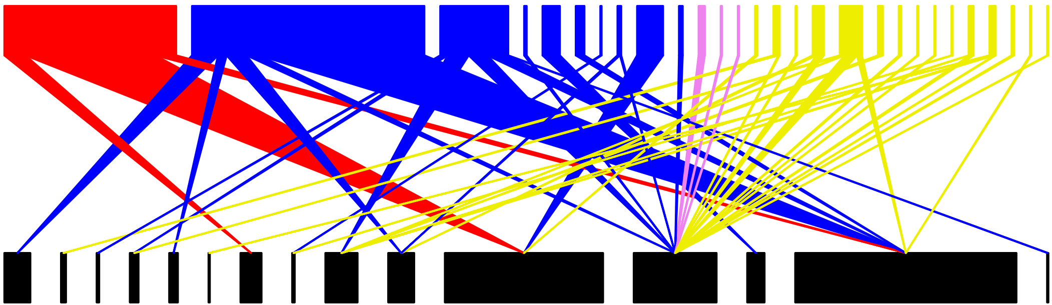
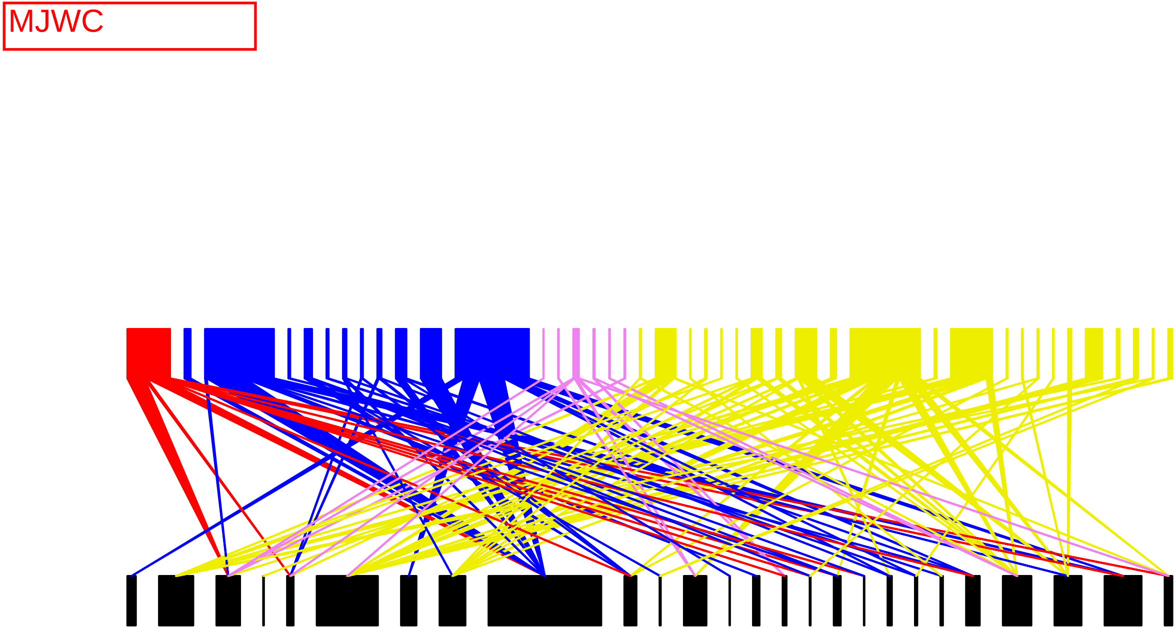
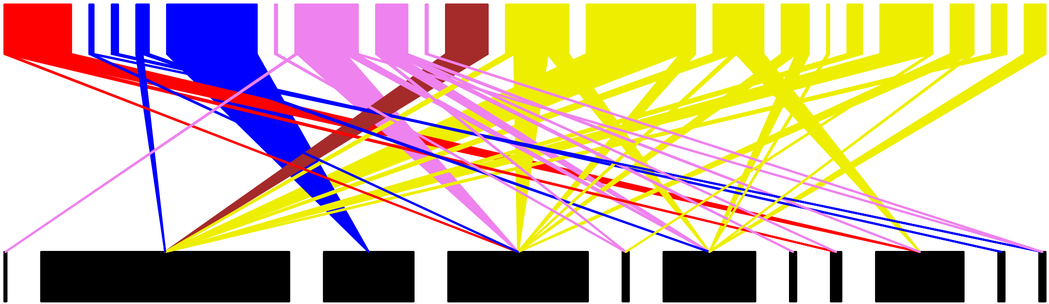


JFWY

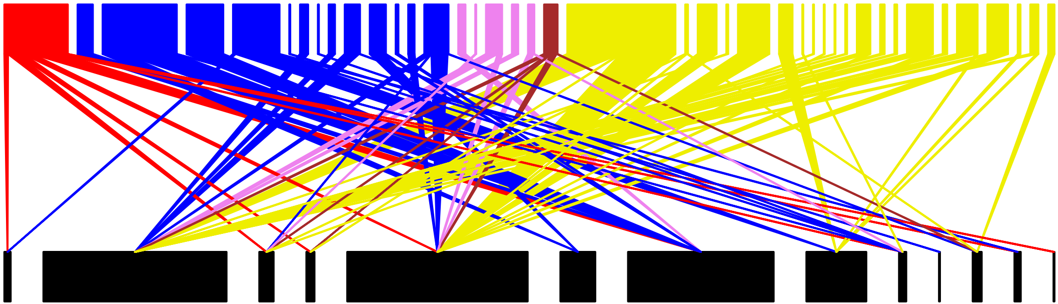



MJWC

HEG



XLWTY



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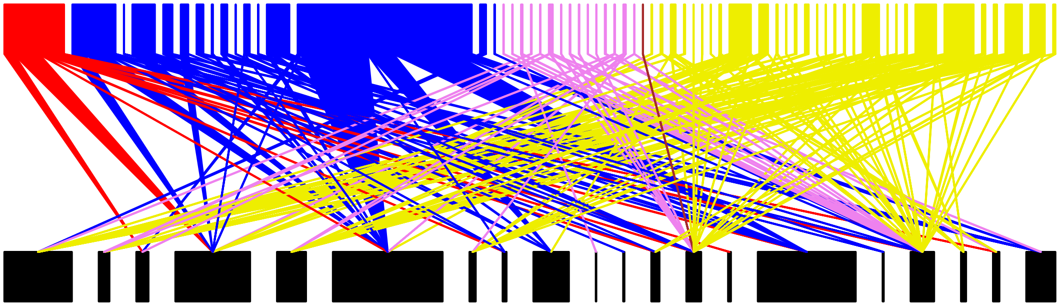

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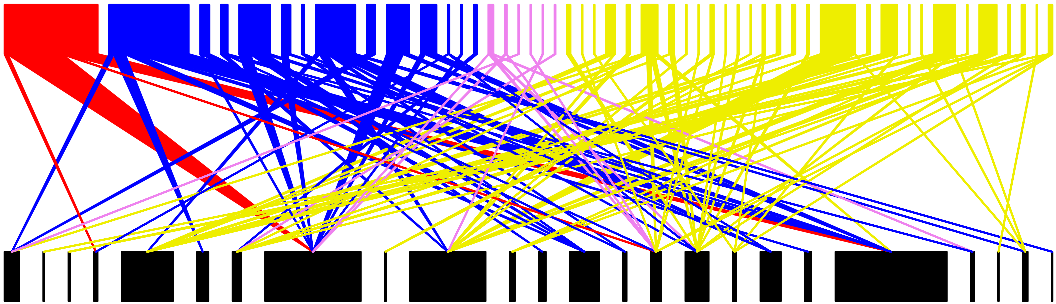

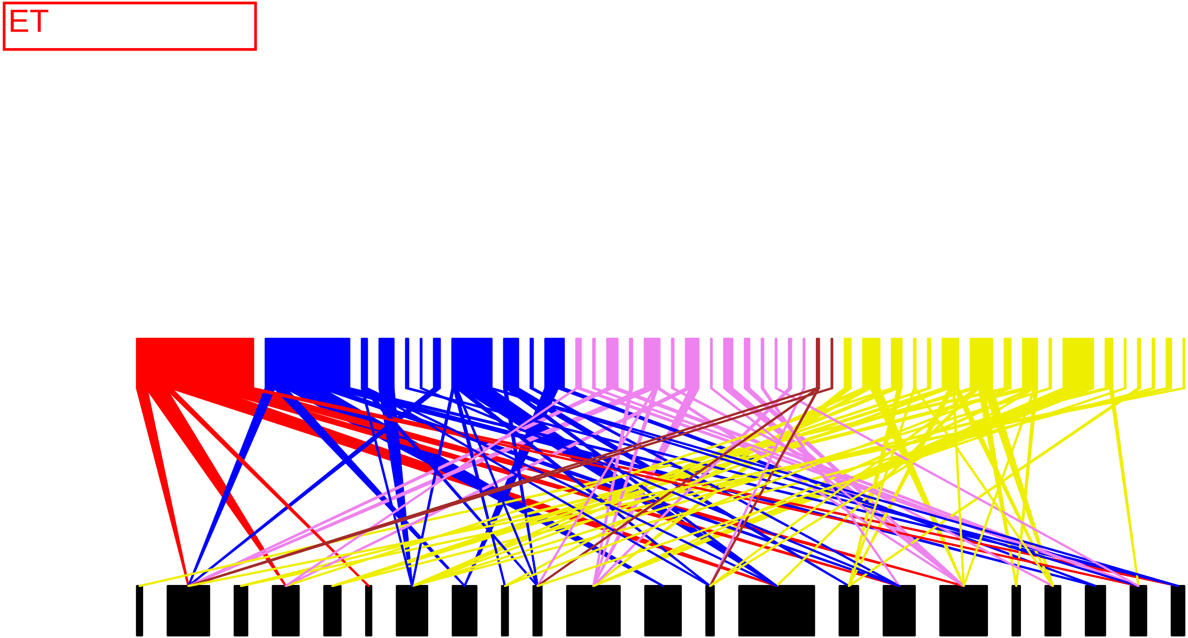
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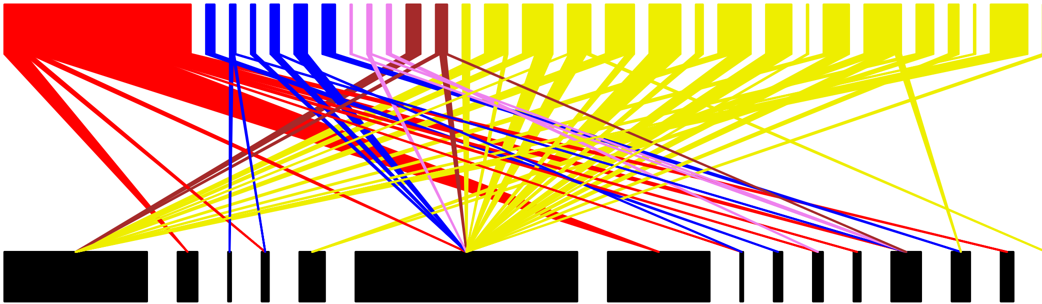

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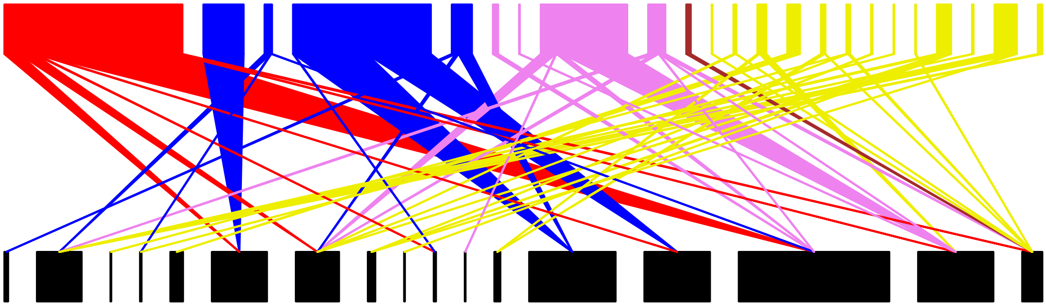
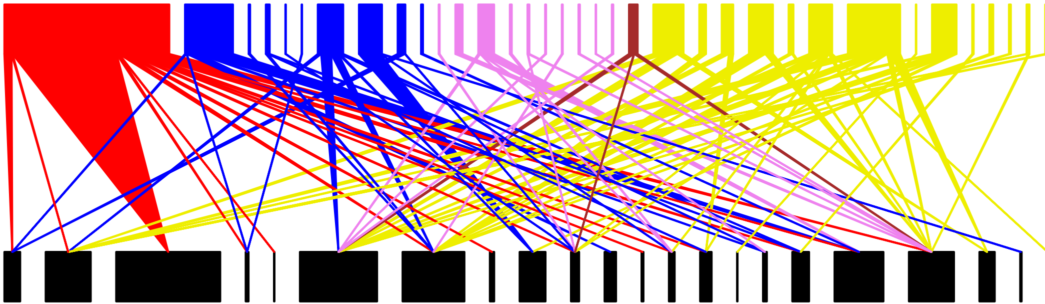


BHXZXXX



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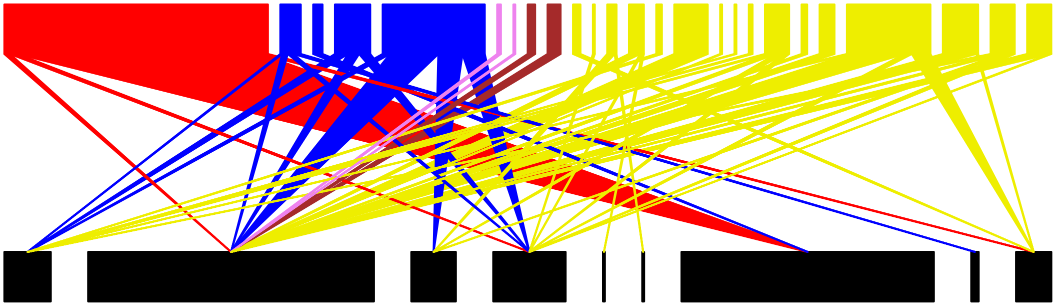

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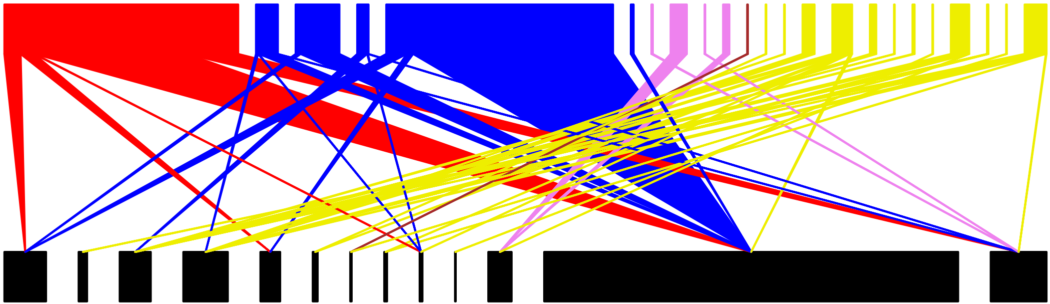
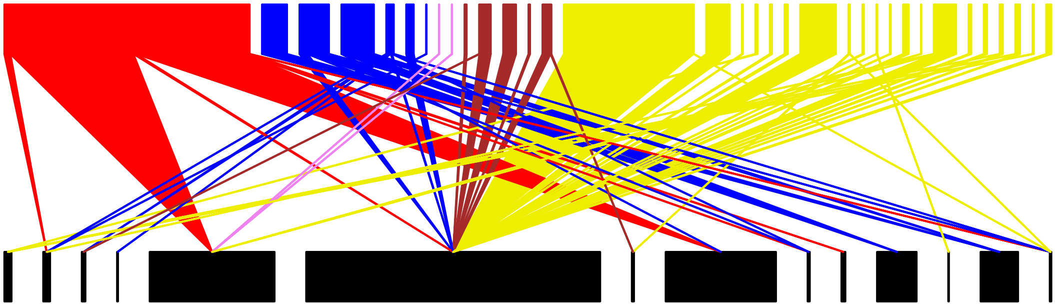



XZC

XLWTC



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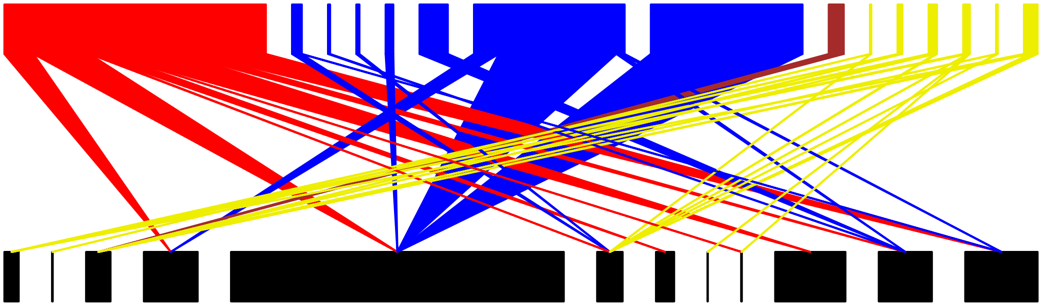

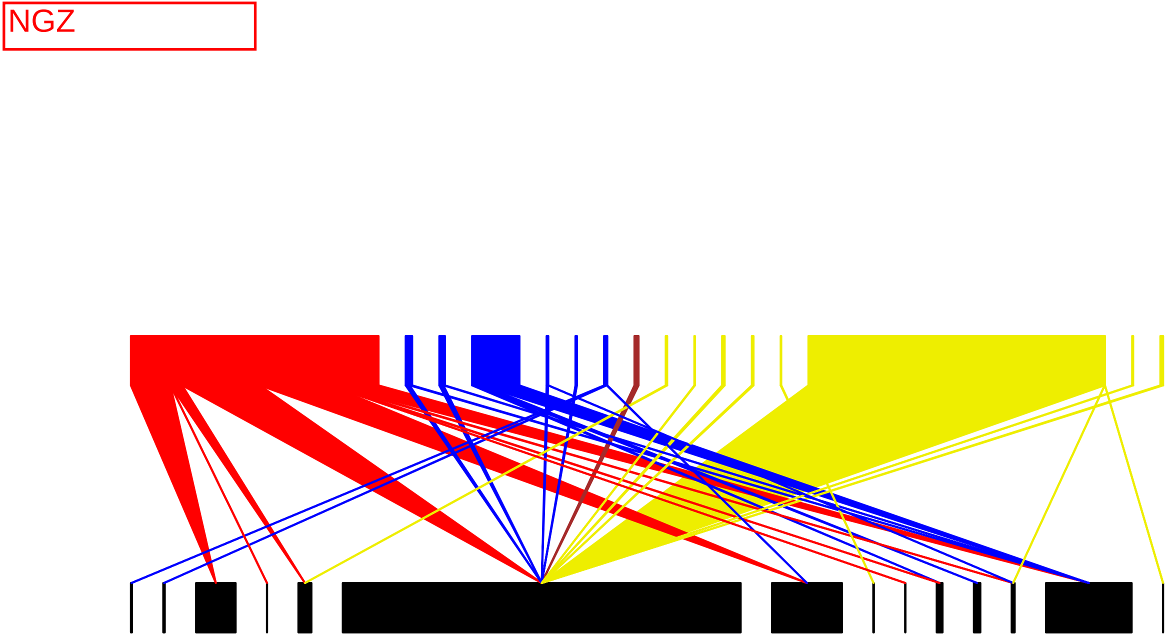
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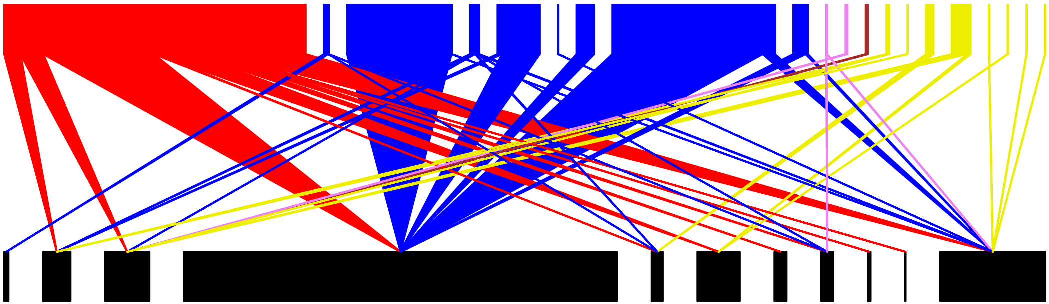

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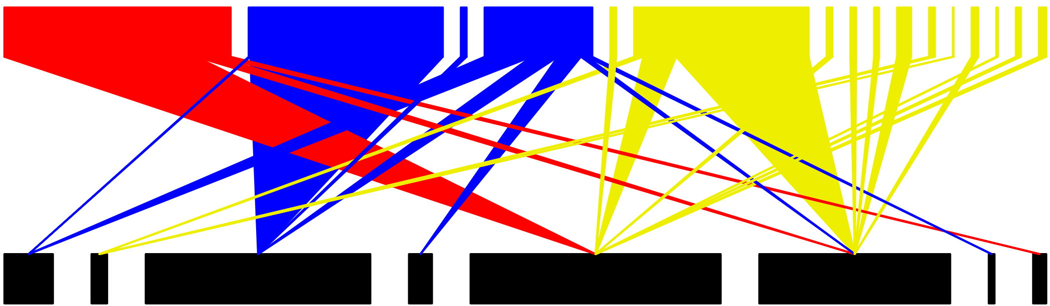

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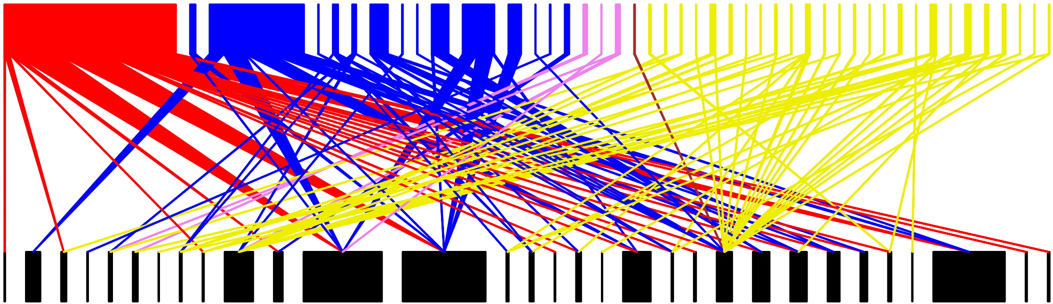

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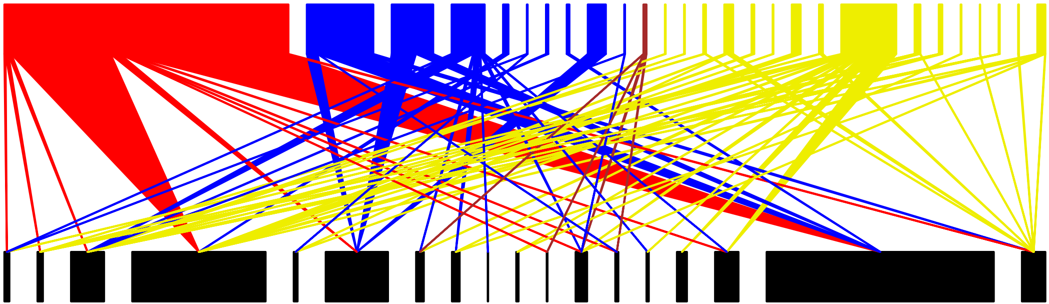

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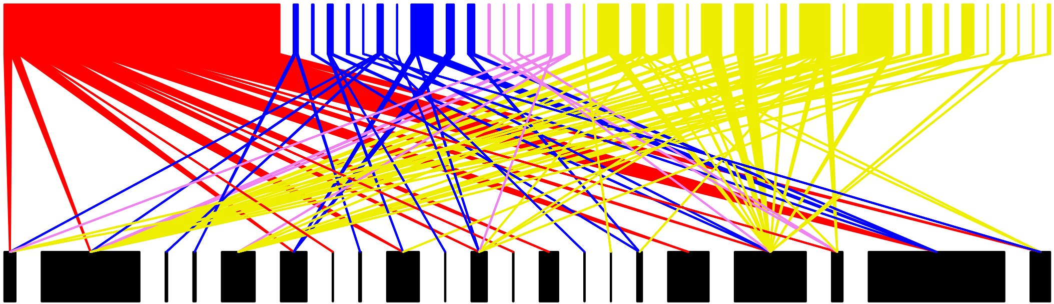
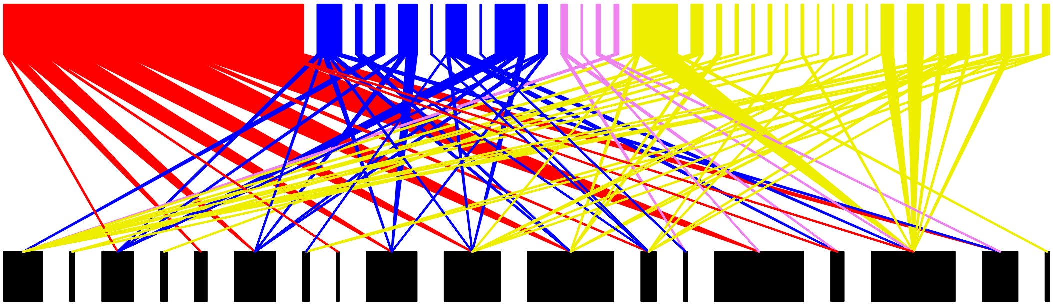


TETC



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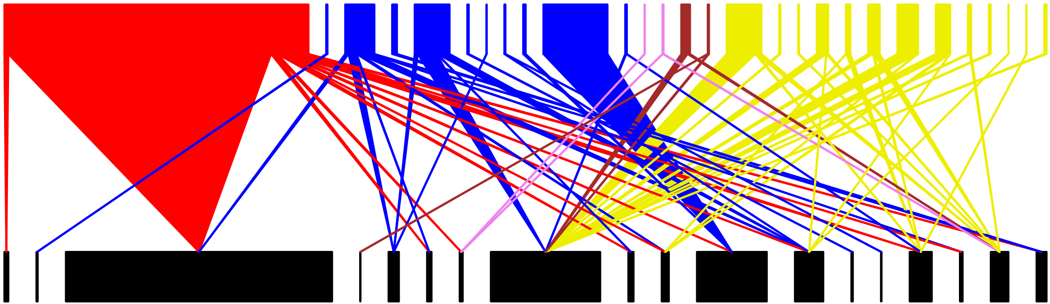

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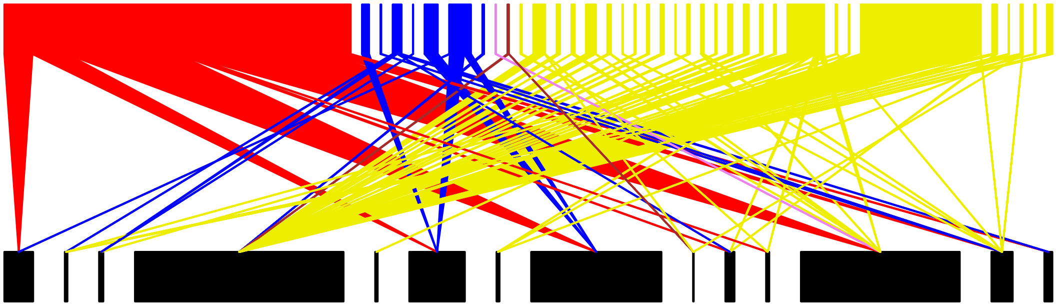

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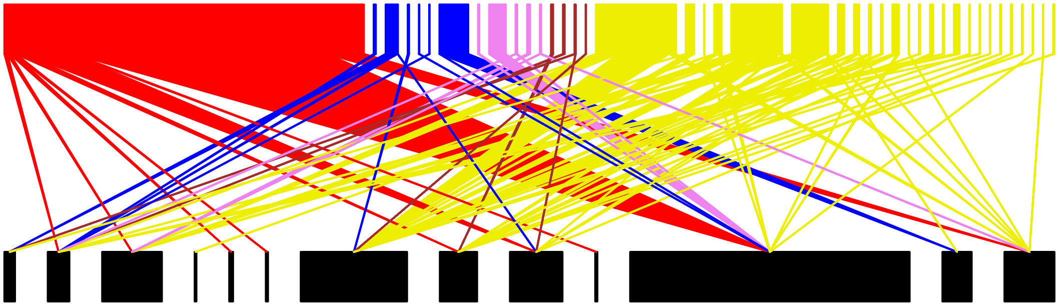

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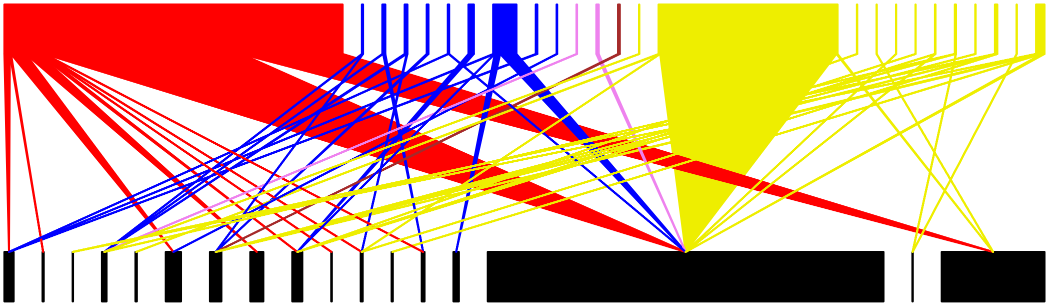

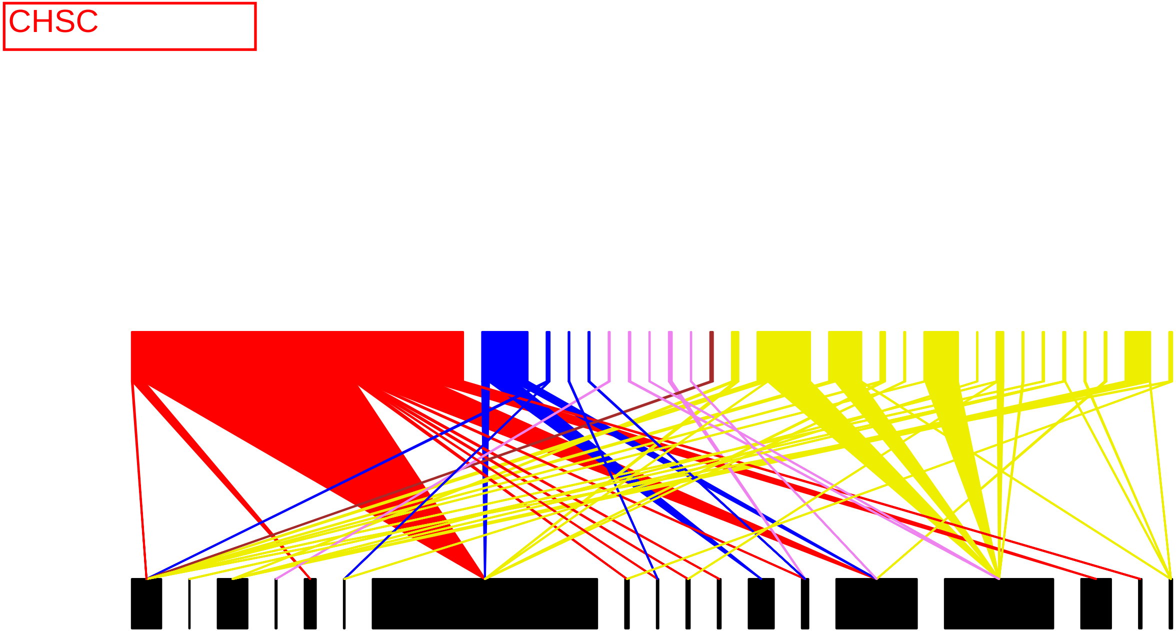
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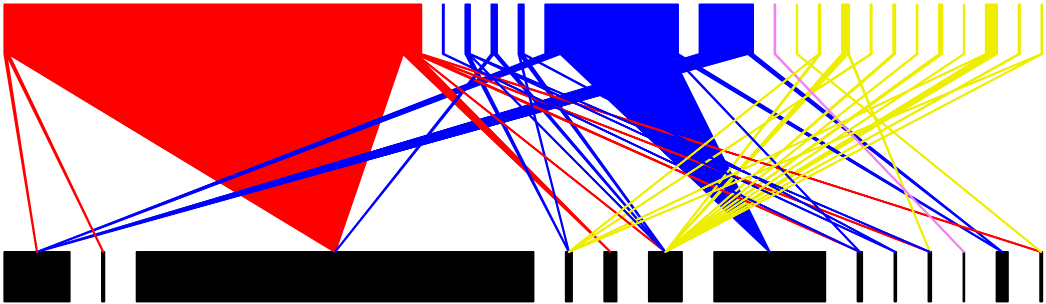

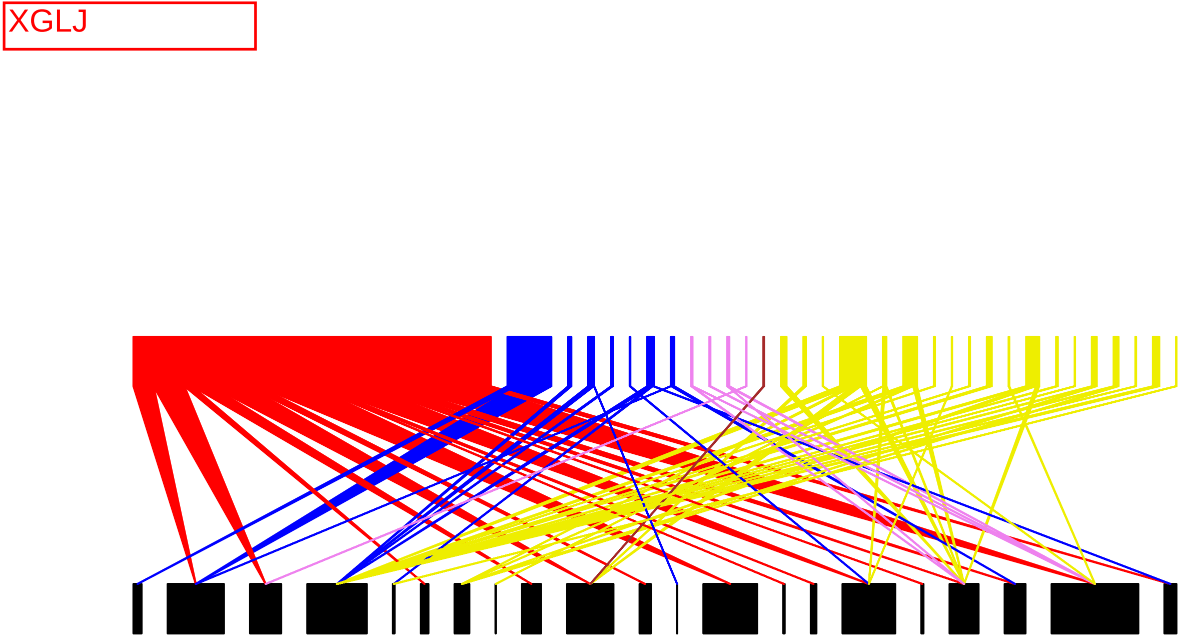
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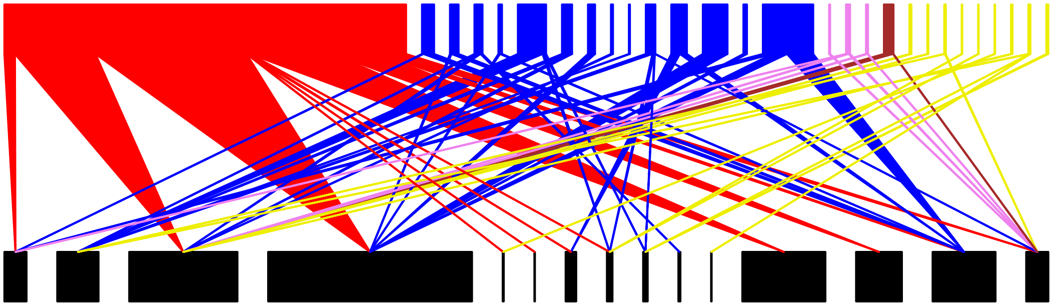

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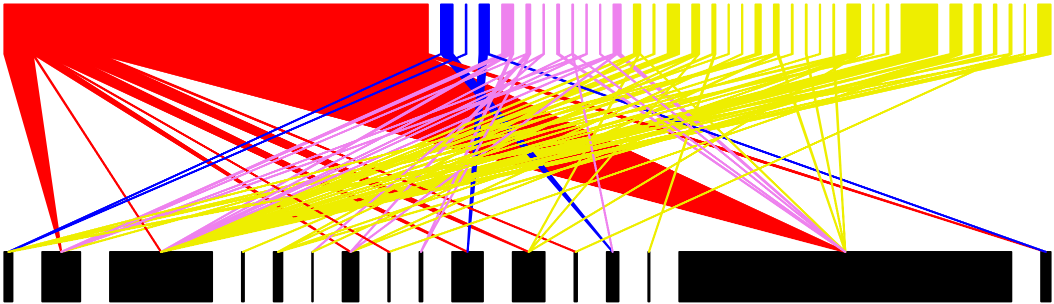

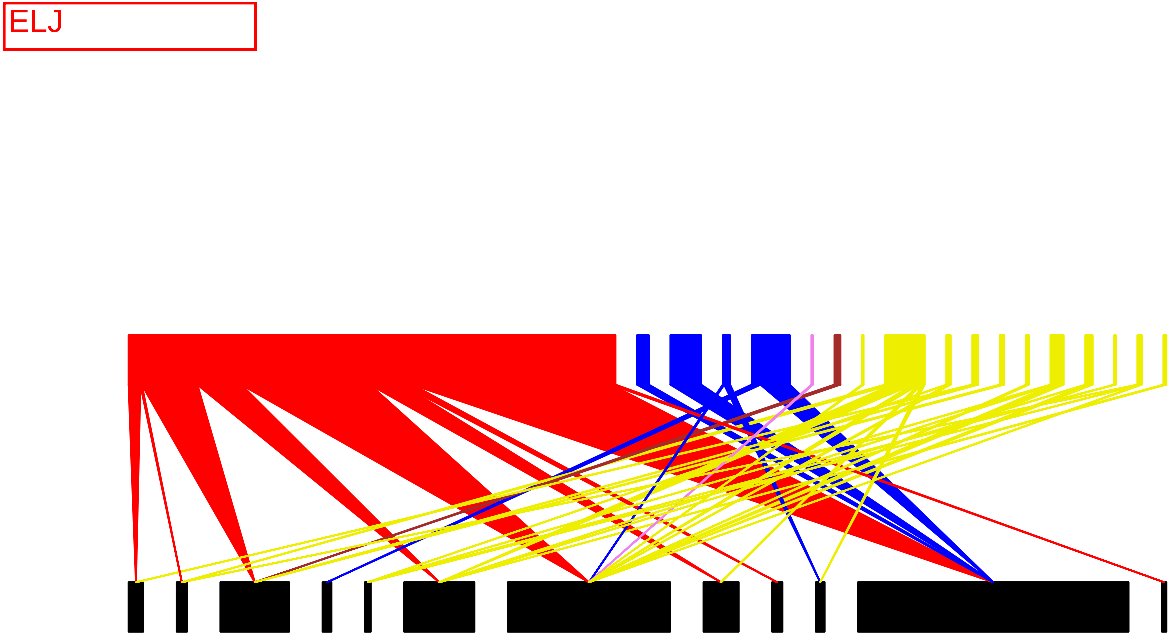
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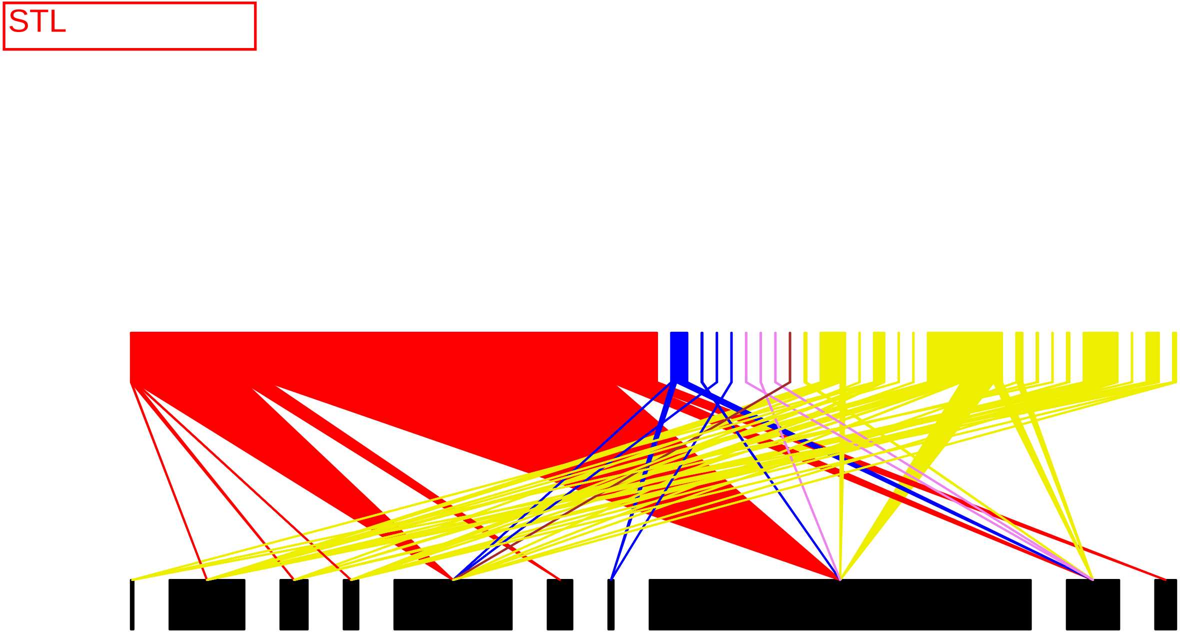

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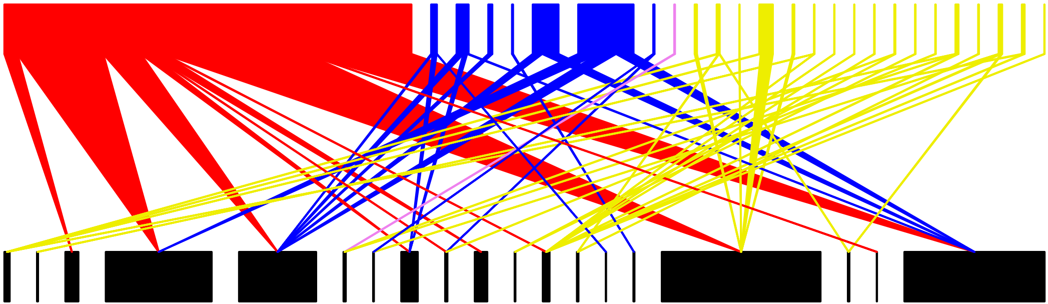

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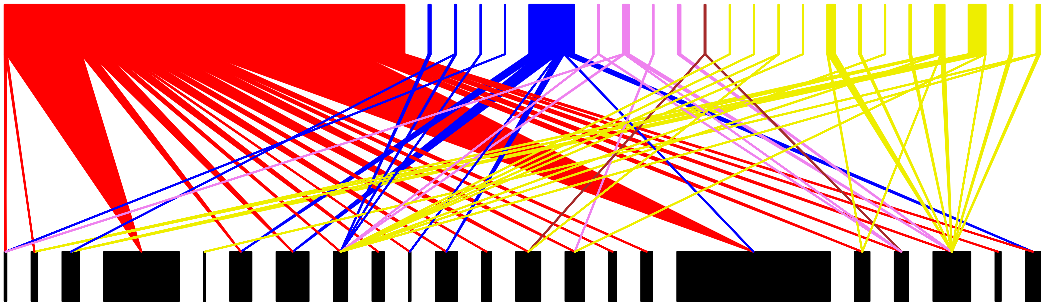

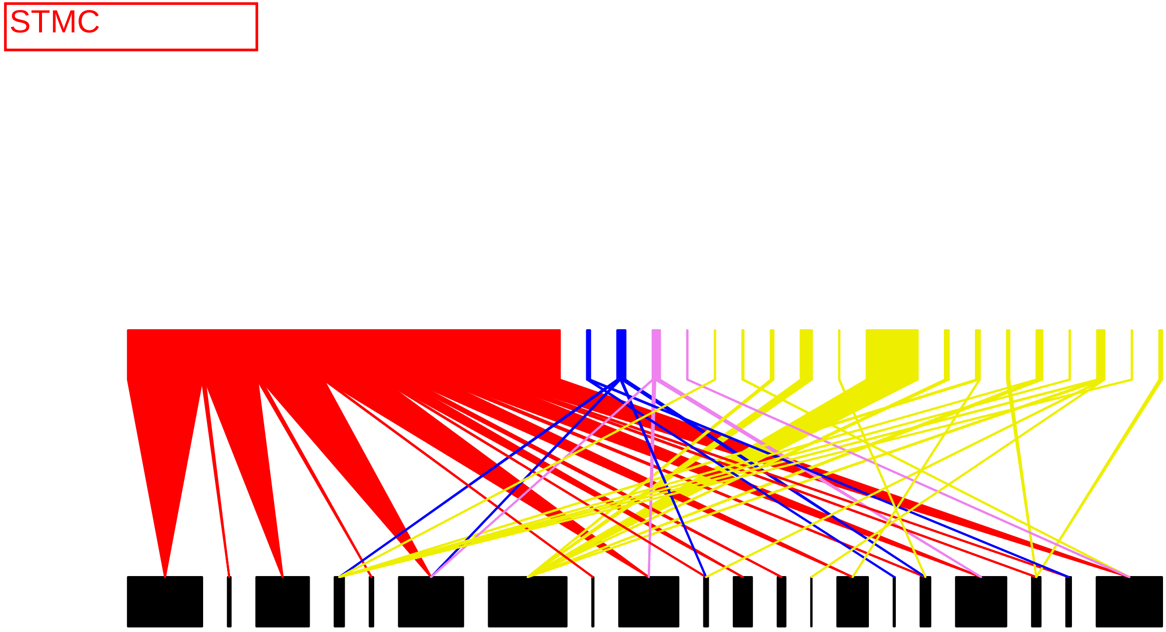
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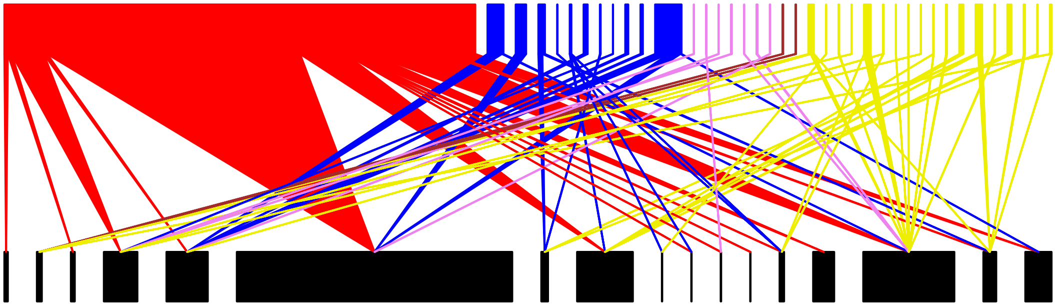

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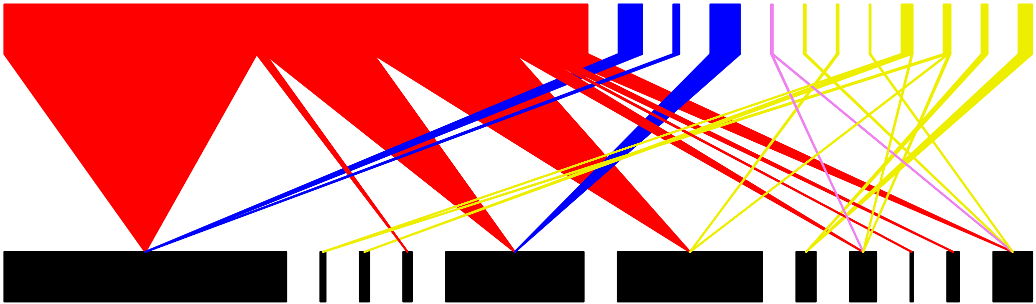

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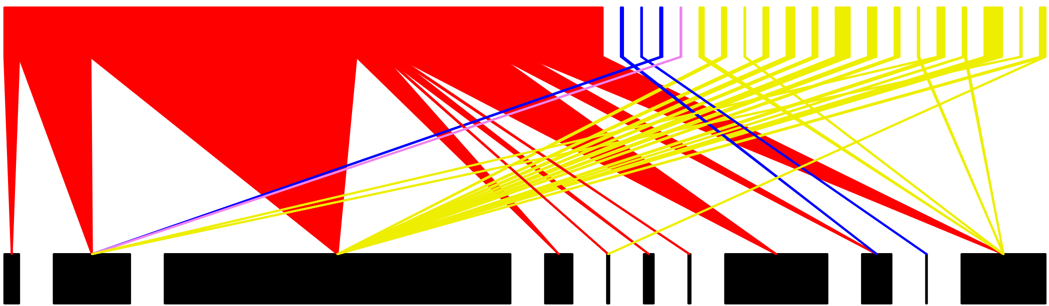

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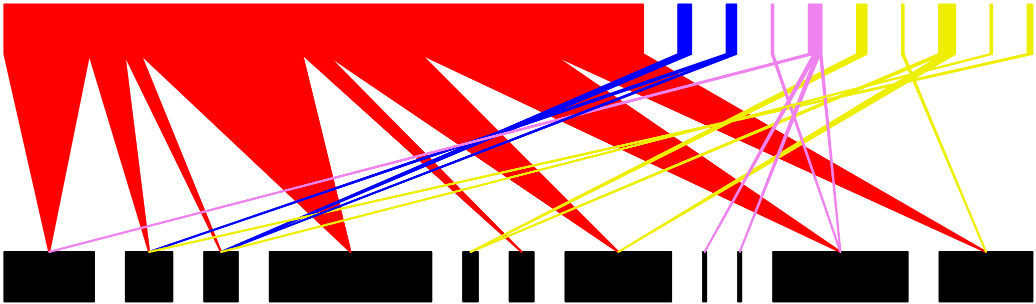

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