

Supplementary materials

Disruption of biological processes in the Anthropocene: the case of phenological mismatch

February 6, 2022

1 Statistical results

Results of robust regression for disappearances above the null model, after a realistic entropy increase, as illustrated in figure 9E,F.

	Estimate	Std. Error	Pr(> t)
(Intercept)	1.4	0.54	0.010
latitude	-0.035	0.0089	0.00024
time	-7.4×10^{-4}	2.7×10^{-4}	0.0088
latitude:time	1.8×10^{-5}	4.9×10^{-6}	0.00025

Table 1: Case $R = 0$ and $a = 0$

	Estimate	Std. Error	Pr(> t)
(Intercept)	0.70	0.28	0.015
latitude	-0.016	0.0042	0.00046
time	-3.6×10^{-4}	1.4×10^{-4}	0.013
latitude:time	7.8×10^{-6}	2.1×10^{-6}	0.00046

Table 2: Case $R = 0.2$ and $a = 0$

	Estimate	Std. Error	Pr(> t)
(Intercept)	1.1	0.52	0.038
latitude	-0.02	8.7×10^{-3}	0.023
time	-5.6×10^{-4}	2.6×10^{-4}	0.037
latitude:time	1.0×10^{-5}	4.4×10^{-6}	0.023

Table 3: Case $R = 0$ and $a = 0.1$

	Estimate	Std. Error	Pr(> t)
(Intercept)	0.82	0.23	0.00067
latitude	-0.015	0.0039	6.7×10^{-5}
time	-4.1×10^{-4}	1.1×10^{-4}	0.00061
latitude:time	7.7×10^{-6}	1.8×10^{-6}	6.9×10^{-5}

Table 4: Case $R = 0.2$ and $a = 0.1$

2 Datasets for historical trends

ID	Species	Interactions	Connectance	Publication date	Observation date	Locality of Studi	Latitude	Longitude
001	185	361	0.043	1981	1981	Cordón del Cepo, Chile	-33.28	-70.27
003	61	81	0.09	1981	1981	Cordón del Cepo, Chile	-33.28	-70.27
004	114	167	0.136	1979	1979	Central New Brunswick, Canada	46.55	-66.07
006	78	146	0.141	2002	2000	Hickling, Norfolk, UK	52.76	1.58
007	52	85	0.148	2002	2000	Shelfanger, Norfolk, UK	52.41	1.1
008	49	106	0.254	2001	2001	Tenerife, Canary Islands	28.22	-16.63
009	142	242	0.085	1994	1994	Latnjajaure, Abisko, Sweden	68.35	18.5
011	27	52	0.286	1999	1999	Mauritius Island	-20.35	57.55
013	65	103	0.204	2001	2001	KwaZulu-Natal region, South Africa	-29.62	30.13
014	110	179	0.076	1968	1966	Hazen Camp, Ellesmere Island, Canada	81.82	-71.3
015	797	2933	0.034	1991	1989	Daphní, Athens, Greece	38.01	23.64
016	205	412	0.089	1983	1983	Doñana Nat. Park, Spain	37.02	-6.55
017	104	299	0.151	1997	1997	Bristol, England	51.57	-2.59
019	125	264	0.078	1984	1984	Snowy Mountains, Australia	-36.45	148.27
020	111	190	0.104	1970	1968	Hazen Camp, Ellesmere Island, Canada	81.82	-71.3
021	768	1193	0.019	1986	1986	Ashu, Kyoto, Japan	35.33	135.75
022	66	83	0.088	1995	1995	Laguna Diamante, Mendoza, Argentina	-34.17	-69.7
023	95	125	0.075	1996	1996	Rio Blanco, Mendoza, Argentina	-33	-69.28
024	29	38	0.192	1967	1965	Melville Island, Canada	75	-114.97
025	57	143	0.25	1982	1980	North Carolina, USA	36.08	-79
028	180	374	0.066	1977	1977	Cass, New Zealand	-43.03	171.78
029	167	346	0.06	1977	1977	Craigieburn, New Zealand	-43.1	171.72
030	81	109	0.073	1986	1986	Guarico State, Venezuela	8.93	-67.42
031	97	156	0.066	1989	1989	Canaima Nat. Park, Venezuela	5.58	-61.72
032	40	65	0.281	1975	1975	Brownfield, Illinois, USA	40.13	-88.17
033	47	141	0.319	1976	1974	Ottawa, Canada	45.4	-75.5
034	154	312	0.094	2001	2001	Chiloe, Chile	-42	-73.58
035	97	178	0.081	1974	1972	Morant Point, Jamaica	17.92	-76.19
037	50	72	0.18	2005	2003	Hestehaven, Denmark	56.25	9.97
038	50	79	0.235	2005	2003	Hestehaven, Denmark	56.24	9.99
039	68	129	0.149	2003	2001	Tenerife, Canary Islands	28.27	-16.61
040	72	114	0.091	2006	2004	Windsor, The Cockpit Country, Jamaica	18.35	-77.65
041	74	145	0.109	2006	2004	Syndicate, Dominica	15.52	-61.47
042	18	25	0.347	2006	2004	Puerto Villamil, Isabela Island, Galapagos	-0.95	-90.98
043	110	250	0.109	2005	2003	Hestehaven, Denmark	56.24	9.95
044	719	1125	0.017	1998	1998	Amami-Oshima Island, Japan	28.38	129.49
045	43	63	0.143	2002	2002	Ummannaq Island, Greenland	71	-52
046	60	278	0.395	2003	2001	Denmark	56.07	10.23
047	205	425	0.12	2004	2004	Isenbjerg	56.07	9.27
048	266	671	0.095	2005	2005	Denmark	56.1	9.1
049	262	590	0.071	2006	2004	Denmark	56.07	10.22
050	49	86	0.176	2003	2001	Tenerife, Canary Islands	28.27	-16.61
051	104	164	0.13	2001	2001	Nahuel Huapi National Park, Argentina	-41.08	-71.53
052	54	92	0.157	1998	1996	Tundra, Greenland	66.97	-50.55
053	393	589	0.02	2001	2001	Mt. Yufu, Japan	33.4	131.5
054	431	773	0.022	1986	1986	Kyoto City, Japan	35.03	135.78
055	259	431	0.035	1995	1995	Nakaikemi marsh, Fukui Prefecture, Japan	35.65	136.08
056	456	871	0.026	1991	1991	Mt. Kushigata, Yamanashi Pref., Japan	35.58	138.38

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ID	Species	Interactions	Connectance	Publication	Observation	Locality of Studi	Latitude	Longitude
057	997	1920	0.019	1986	1986	Kibune, Kyoto, Japan	35.17	135.87
058	113	319	0.123	2005	2005	Parc Natural del Cap de Creus	42.3	3.24
059	26	71	0.42	2005	2005	Parque Nacional do Catimbau	-8.51	-37.2
060_04	67	134	0.139	2004	2004	Black River Gorges National Park, Mauritius	-20.7	57.73
060_16	56	114	0.172	2004	2004	Black River Gorges National Park, Mauritius	-20.7	57.73
061_06	35	58	0.22	2008	2008	Morne Seychellois National Park, Mahé	-4.67	55.43
061_40	35	58	0.248	2008	2008	Morne Seychellois National Park, Mahé	-4.67	55.43
063	64	123	0.248	2012	2012	Santa Virginia Field Station, Serra do Mar State Park	-23.34	-45.12
064	22	32	0.286	1999	1999	Reserva Florestal Mata do Paraíso, Brazil	-20.75	-42.92
065	26	44	0.419	1986	1986	Estacion de Biologia Chamela, Jalisco	19.5	-105.05
066	36	73	0.471	2006	2004	Serra da Mantiqueira, PNI, SE Brazil	-22.5	-44.83
067	36	59	0.263	2008	2008	Serra do Pará, Brazil	-7.87	-36.4
068	40	83	0.297	2000	2000	Santuario de Flora y Fauna Galeras	1.25	-77.43
069_01	24	29	0.269	2010	2010	Atlantic Forest, low elevation	-27.27	-49.01
069_02	14	16	0.4	2010	2010	Atlantic Forest, mid elevation	-27.26	-49.02
070	16	41	0.641	2006	2004	Highland temperate mosaic forest, Central Mexico	19.23	-98.97
071	52	89	0.253	2003	2001	Rainforest, Colombia	0.04	-72.27
072_01	106	188	0.072	2008	2008	Amarante, Pampas, Argentina	-37.84	-58.36
072_02	96	171	0.082	2008	2008	Cinco Cerros, Pampas, Argentina	-37.74	-58.23

Table 5: Details of the networks used, source: www.web-of-life.es.

ID	Reference
001	Arroyo, M.T.K., R. Primack & J.J. Armesto. 1982. Community studies in pollination ecology in the high temperate Andes of central Chile. I. Pollination mechanisms and altitudinal variation. Amer. J. Bot. 69:82-97.
003	Arroyo, M.T.K., R. Primack & J.J. Armesto. 1982. Community studies in pollination ecology in the high temperate Andes of central Chile. I. Pollination mechanisms and altitudinal variation. Amer. J. Bot. 69:82-97.
004	Barrett, S. C. H., and K. Helenurm. 1987. The Reproductive-Biology of Boreal Forest Herbs.1. Breeding Systems and Pollination. Canadian Journal of Botany 65:2036-2046.
006	Dicks, LV, Corbet, SA and Pywell, RF 2002. Compartmentalization in plantinsect flower visitor webs. J. Anim. Ecol. 71: 3243.
007	Dicks, LV, Corbet, SA and Pywell, RF 2002. Compartmentalization in plantinsect flower visitor webs. J. Anim. Ecol. 71: 3243.
008	Dupont YL, Hansen DM and Olesen JM (2003) Structure of a plant-flower-visitor network in the high-altitude sub-alpine desert of Tenerife, Canary Islands. Ecography 26:301-310.
009	Elberling, H. & Olesen, J. M. 1999. The structure of a high latitude plant-pollinator system: The dominance of flies. Ecography 22:314-323.
011	Olesen, J.M., Eskildsen, L.I. & Venkatasamy, S. (2002). Div. Distr., 8:181-192.
013	Ollerton, J., S. D. Johnson, L. Cranmer, and S. Kellie. 2003. The pollination ecology of an assemblage of grassland asclepiads in South Africa. Annals of Botany 92:807-834.
014	Hocking, B. 1968. Insect-flower associations in the high Arctic with special reference to nectar. Oikos 19:359-388.
015	Petanidou, T. (1991). Pollination ecology in a phryganic ecosystem. Unp. PhD. Thesis, Aristotelian University, Thessaloniki.
016	Herrera, J. (1988) Pollination relationships in southern spanish mediterranean shrublands. Journal of Ecology 76: 274-287.
017	Memmott J. 1999. The structure of a plant-pollinator food web. Ecology Letters 2:276-280.
019	Inouye, D. W., and G. H. Pyke. 1988. Pollination biology in the Snowy Mountains of Australia: comparisons with montane Colorado, USA. Australian Journal of Ecology 13:191-210.
020	Kevan P. G. 1970. High Arctic insect-flower relations: The interrelationships of arthropods and flowers at Lake Hazen, Ellesmere Island, Northwest Territories, Canada. Ph.D. thesis, University of Alberta, Edmonton, 399 pp.
021	Kato, M., Kakutani, T., Inoue, T. and Itino, T. (1990). Insect-flower relationship in the primary beech forest of Ashu, Kyoto: An overview of the flowering phenology and the seasonal pattern of insect visits. Contrib. Biol. Lab., Kyoto, Univ., 27, 309-375.
022	Medan, D., N. H. Montaldo, M. Devoto, A. Mantese, V. Vasellati, and N. H. Bartoloni. 2002. Plant-pollinator relationships at two altitudes in the Andes of Mendoza, Argentina. Arctic Antarctic and Alpine Research 34:233-241.

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ID	Reference
023	Medan, D., N. H. Montaldo, M. Devoto, A. Mantese, V. Vasellati, and N. H. Bartoloni. 2002. Plant-pollinator relationships at two altitudes in the Andes of Mendoza, Argentina. <i>Arctic Antarctic and Alpine Research</i> 34:233-241.
024	Mosquin, T., and J. E. H. Martin. 1967. Observations on the pollination biology of plants on Melville Island, N.W.T., Canada. <i>Canadian Field Naturalist</i> 81:201-205.
025	Motten, A. F. 1982. Pollination Ecology of the Spring Wildflower Community in the Deciduous Forests of Piedmont North Carolina. Doctoral Dissertation thesis, Duke University, Durham, North Carolina, USA; Motten, A. F. 1986. Pollination ecology of the spring wildflower community of a temperate deciduous forest. <i>Ecological Monographs</i> 56:21-42.
028	Primack, R.B. (1983). Insect pollination in the New Zealand mountain flora. <i>New Zealand J. Bot.</i> 21, 317-333. Cass.
029	Primack, R.B. (1983). Insect pollination in the New Zealand mountain flora. <i>New Zealand J. Bot.</i> 21, 317-333. Craigieb.
030	Ramirez, N., and Y. Brito. 1992. Pollination Biology in a Palm Swamp Community in the Venezuelan Central Plains. <i>Botanical Journal of the Linnean Society</i> 110:277-302.
031	Ramirez, N. (1989). <i>Biología de polinización en una comunidad arbustiva tropical de la alta Guyana Venezolana</i> . <i>Biotropica</i> 21, 319-330.
032	Schemske, D. W., M. F. Willson, M. N. Melampy, L. J. Miller, L. Verner, K. M. Schemske, and L. B. Best. 1978. Flowering Ecology of Some Spring Woodland Herbs. <i>Ecology</i> 59:351-366.
033	Small, E. 1976. Insect pollinators of the Mer Bleue peat bog of Ottawa. <i>Canadian Field Naturalist</i> 90:22-28.
034	Smith-Ramírez C., P. Martinez, M. Nuñez, C. González and J. J. Armesto (2005) Diversity, flower visitation frequency and generalism of pollinators in temperate rain forests of Chiloé Island, Chile. <i>Botanical Journal of the Linnean Society</i> , 2005, 147, 399-416.
035	Percival, M. (1974). Floral Ecology of Coastal Scrub in Southeast Jamaica. <i>Biotropica</i> , 6, 104-129.
037	Montero AC (2005). The Ecology of Three Pollination Networks. MSc thesis (Univ of Aarhus, Aarhus, Denmark).
038	Montero AC (2005). The Ecology of Three Pollination Networks. MSc thesis (Univ of Aarhus, Aarhus, Denmark).
039	Stald L (2003). Struktur og dynamik i rum og tid af et bestøvningsnetværk på Tenerife, De Kanariske Øer. Msc thesis (Univ of Aarhus, Aarhus, Denmark).
040	Ingversen TT (2006). Plantpollinator interactions on Jamaica and Dominica: The centrality, asymmetry and modularity of networks. Msc thesis (Univ of Aarhus, Aarhus, Denmark).
041	Ingversen TT (2006) MSc thesis (Univ of Aarhus, Aarhus, Denmark). (MSc, 2006, Tanja Toftemark Ingversen, Plantpollinator interactions on Jamaica and Dominica: The centrality, asymmetry and modularity of networks)
042	Philipp M, Böcher J, Siegmund HR, Nielsen LR (2006) <i>Ecography</i> 29:531-540. (Philipp, M., Böcher, J., Siegmund, H. R. and Nielsen, L. R. 2006. Structure of a plant-pollinator network on a pahoehoe lava desert of the Galápagos Islands. <i>Ecography</i> 29: 531-540.)
043	Montero AC (2005). The Ecology of Three Pollination Networks. MSc thesis (Univ of Aarhus, Aarhus, Denmark).
044	Kato M (2000). Anthophilous insect community and plant-pollinator interactions on Amami Islands in the Ryukyu Archipelago, Japan. <i>Contr Biol Lab Kyoto Univ</i> 29:157-252.
045	Lundgren R, Olesen JM (2005). The Dense and Highly Connected World of Greenland's Plants and Their Pollinators. <i>Arc Antarc Alp Res</i> 37:514-520.
046	Bundgaard, M. (2003). Tidslig og rumlig variation i et plante-bestøvningsnetværk. Msc thesis. University of Aarhus. Aarhus, Denmark.
047	Dupont & Olesen (2009). <i>J. Animal Ecology</i> , 78:346-353.
048	Dupont & Olesen (2009). <i>J. Animal Ecology</i> , 78:346-353.
049	Bek S (2006). A pollination network from a Danish forest meadow. MSc thesis (Univ of Aarhus, Aarhus, Denmark).
050	Stald, L., Valido, A. & Olesen, J. M. 2003. Struktur og dynamik i rum og tid af et bestøvningsnetværk på Tenerife, De Kanariske Øer. MSc-thesis, Univ. of Aarhus, Denmark.
051	Vázquez DP. 2002. Interactions among Introduced Ungulates, Plants, and Pollinators: A Field Study in the Temperate Forest of the Southern Andes. Ph.D. Dissertation. Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville.
052	Witt P (1998) BSc thesis. Univ of Aarhus, Aarhus, Denmark.
053	Yamazaki, K. & Kato, M. 2003. Flowering phenology and anthophilous insect community in a grassland ecosystem at Mt. Yufu, Western Japan. <i>Contributions from the Biological Laboratory, Kyoto University</i> 29: 255-318.
054	Kakutani, T., T. Inoue, M. Kato and H. Ichihashi (1990) Insect-flower relationship in the campus of Kyoto University, Kyoto: An overview of the flowering phenology and the seasonal pattern of insect visits. <i>Contribution from the Biological Laboratory, Kyoto University</i> , 27: 465-521.
055	Kato & Miura (1996). Flowering phenology and anthophilous insect community at a threatened natural lowland marsh at Nakaikemi in Tsuruga, Japan. <i>Kyoto University, Vol. 29: 1-48</i>
056	Kato et al. 1993. Flowering Phenology and Anthophilous Insect Community in the Cool-Temperate Subalpine Forests and Meadows at Mt. Kushigata in the Central Part of Japan. <i>Contributions from the Biological Laboratory, Kyoto University</i> 28: 119-172
057	Inoue et al 1990. Insect-flower Relationship in the Temperate Deciduous Forest of Kibune, Kyoto : An Overview of the Flowering Phenology and the Seasonal Pattern of Insect Visits.
058	Bartomeus, I., Vilà, M. & Santamaria, L., 2008. Contrasting effects of invasive plants in plant-pollinator networks. <i>Oecologia</i> 155: 761-770.

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ID	Reference
059	Bezerra ELS, Machado ICS, Mello MAR. 2009. Pollination networks of oil-flowers: a tiny world within the smallest of all worlds. <i>Journal of Animal Ecology</i> 78:10961101.
060_04	Kaiser-Bunbury, C. N., S. Muff, J. Memmott, C. B. Müller, and A. Caffisch. 2010. The robustness of pollination networks to the loss of species and interactions: A quantitative approach incorporating pollinator behaviour. <i>Ecology Letters</i> 13:442-452.
060_16	Kaiser-Bunbury, C. N., S. Muff, J. Memmott, C. B. Müller, and A. Caffisch. 2010. The robustness of pollination networks to the loss of species and interactions: A quantitative approach incorporating pollinator behaviour. <i>Ecology Letters</i> 13:442-452.
061_06	Kaiser-Bunbury CN, Vázquez DP, Stang M, Ghazoul J. 2014. Determinants of the microstructure of plant-pollinator networks. <i>Ecology</i> , 95: 3314-3324.
061_40	Kaiser-Bunbury CN, Vázquez DP, Stang M, Ghazoul J. 2014. Determinants of the microstructure of plant-pollinator networks. <i>Ecology</i> , 95: 3314-3324.
063	Vizentin-Bugoni, J., P. K. Maruyama, V. J. Debastiani, L. S. Duarte, B. Dalsgaard & M. Sazima (2016). Influences of sampling effort on detected patterns and structuring processes of a Neotropical plant-hummingbird network. <i>Journal of Animal Ecology</i> 85: 262-272.
064	Abreu, C.R.M. & Vieira, M.F. (2004) Os beija-flores e seus recursos florais em um fragmento florestal de Viçosa, sudeste brasileiro. <i>Lundiana</i> , 5, 129134.
065	Arizmendi, M.C. & Ornelas, J.F. (1990) Hummingbirds and their floral resources in a tropical dry forest inforest, in Mexico. <i>Biotropica</i> , 22, 172180.
066	Canela, M.B.F. (2006) Interações entre plantas e beija-flores numa comunidade de floresta atlântica montana em Itatiaia, RJ. Ph.D thesis. Universidade Estadual de Campinas, Brazil.
067	Las Casas, F.M.G., Azevedo Júnior, S.M. & Dias Filho, M.M. (2012) The community of hummingbirds(Aves: Trochilidae) and the assemblage of flowers in a Caatinga vegetation. <i>Brazilian Journal of Biology</i> ,72, 5158.
068	Gutierrez Zamora, E.A. & Rojas Nossa, S.V. (2001) Dinámica anual de la interacción colibrí-flor en ecosistemas altoandinos del volcán Galeras, Sur de Colombia. BSc. Thesis. Universidad Nacional de Colombia, Colombia.
069_01	Kohler, G. (2011) Redes de interação planta-beija-flor em um gradiente altitudinal de Floresta Atlântica no Sul do Brasil. MSc. Thesis. Universidade Federal do Paraná, Brazil.
069_02	Kohler, G. (2011) Redes de interação planta-beija-flor em um gradiente altitudinal de Floresta Atlântica no Sul do Brasil. MSc. Thesis. Universidade Federal do Paraná, Brazil.
070	Lara, C. (2006) Temporal dynamics of flower use by hummingbirds in a highland temperate forest in México. <i>Eco-science</i> , 13, 2329.
071	Rosero, L. (2003) Interações planta/beija-flor em três comunidades vegetais da parte sul do Parque Nacional Natural Chiribiquete, Amazonas (Colombia). Ph.D. Thesis. Universidade Estadual de Campinas, Brazil
072_01	Sabatino M., Maceira N., Aizen A. M. (2010) Direct effects of habitat area on interaction diversity in pollination webs. <i>Ecological Applications</i> , 20(6), pp. 14911497
072_02	Sabatino M., Maceira N., Aizen A. M. (2010) Direct effects of habitat area on interaction diversity in pollination webs. <i>Ecological Applications</i> , 20(6), pp. 14911497

Table 6: Reference of the networks used, source: www.web-of-life.es.

References

Burkle, L. A., Marlin, J. C., & Knight, T. M. (2013). Data from: Plant-pollinator interactions over 120 years: Loss of species, co-occurrence, and function. Dataset, Dryad.

Memmott, J., Craze, P. G., Waser, N. M., & Price, M. V. (2007). Global warming and the disruption of plantpollinator interactions. *Ecology Letters*, 10, 710–717.