Supplementary material

Table S1: Overview of sites used in this study. Longitude (Lon), Latitude (Lat), long-term mean annual temperature (MAT) and precipitation (MAP) are according to the European Fluxes Database cluster (http://www.europe-fluxdata.eu) for sites in this database, and provided by site PIs accordingly otherwise. Ecosystem refers to the simplified Four-type classification used in this study. Reference years from within the period 2004-2017 were chosen based on data availability and, in case of crop rotation sites, the same crop being grown as in 2018.

Site	Lon	Lat	IGBP	MAT (°C)	MAP (mm)	Elevation (m)	Ecosystem	Reference years	Reference
BE-Bra	4.5	51.3	MF	9.8	750	16	forest	2004-2017	[1]
BE-Lon	4.7	50.6	CRO	10	800	167	crop	2006, 10, 14	[2]
BE-Vie	6.0	50.3	MF	7.8	1062	493	forest	2004-2017	[3]
CH-Aws	9.8	46.6	GRA	2.3	918	1978	grass	2011, 16, 17	[4]
CH-Cha	8.4	47.2	GRA	9.5	1136	400	grass	2006-2017	[5]
CH-Dav	9.9	46.8	ENF	3.5	1046	1639	forest	2004-2017	[6]
CH-Fru	8.5	47.1	GRA	7.2	1651	982	grass	2006-2017	[4]
CH-Lae	8.4	47.5	MF	8.7	1211	689	forest	2005-2017	[6]
CH-Oe2	7.7	47.3	CRO	9.8	1155	452	crop	2008, 2013	[7]
CZ-BK1	18.5	49.5	ENF	6.7	1316	875	forest	2015-2017	[8]
CZ-Lnz	16.9	48.7	MF	9.3	550	150	forest	2016-2017	[9]
CZ-RAJ	16.7	49.4	ENF	7.1	681	625	forest	2013-2017	[10]
CZ-Stn	18.0	49.0	DBF	8.7	685	550	forest	2015-2017	[11]
CZ-wet	14.8	49.0	WET	7.7	604	425	peatland	2007-2017	[12]
DE-BER	13.3	52.2	URB	9.4	525	61	grass	2016-2017	[13]
DE-EC2	8.7	48.9	CRO	9.4	889	318	crop	2011, 13, 15, 17	[14]
DE-EC4	9.8	48.5	CRO	7.5	1064	687	crop	2011, 14, 15	[15]
DE-Fen	11.1	47.8	GRA	8.4	1081	595	grass	2012-2017	[16]
DE-Geb	10.9	51.1	CRO	8.5	470	162	crop	2007, 08, 10, 14, 16	[17]
DE-Gri	13.5	51.0	GRA	7.8	901	385	grass	2005-2017	[18]
DE-Hai	10.5	51.1	DBF	8.3	720	440	forest	2004-2017	[19]
DE-HoH	11.2	52.1	DBF	9.1	563	193	forest	2015-2017	[20]
DE-Hte	12.2	54.2	WET	9.2	645	0	peatland	2016-2017	[21]
DE-Kli	13.5	50.9	CRO	7.6	842	478	crop	2007, 2012	[18]
DE-Obe	13.7	50.8	ENF	5.5	996	734	forest	2009-2017	[18]
DE-RbW	11.0	47.7	GRA	9.0	1160	769	grass	2012-2017	[16]
DE-RuR	6.3	50.6	GRA	7.7	1033	515	grass	2012-2017	[22]
DE-RuS	6.4	50.9	CRO	10.2	718	103	crop	2013, 2015	[23]
DE-RuW	6.3	50.5	ENF	7.5	1250	610	forest	2014-2017	[24]
DE-SfS	11.3	47.8	WET	8.6	1127	590	peatland	2013-2017	[25]
DE-Tha	13.6	51.0	ENF	8.2	843	380	forest	2004-2017	[18]
DE-ZRK	12.9	53.9	WET	8.7	584	1	peatland	2016-2017	[26]
DK-Sor	11.6	55.5	DBF	8.2	660	40	forest	2004-2017	[27]
ES-Abr	-6.8	38.7	SAV	16	400	280	forest	2016-2017	[28]
ES-LM1	-5.8	39.9	SAV	16	700	265	forest	2016-2017	[29]
ES-LM2	-5.8	39.9	SAV	16	700	270	forest	2016-2017	[29]
FI-Hyy	24.3	61.8	ENF	3.8	709	180	forest	2004-2017	[30]
FI-Let	24.0	60.6	ENF	4.6	627	0	forest	2017	[31]
FI-Sii	24.2	61.8	WET	3.5	701	160	peatland	2016-2017	[32]
FI-Var	29.6	67.8	ENF	-0.5	601	395	forest	2017-2017	[33]
FR-Bil	-1.0	44.5	ENF	12.8	930	0	forest	2015-2017	[34]
FR-EM2	3.0	49.9	CRO	10.8	680	84	crop	2015	[35]
FR-Hes	7.1	48.7	DBF	9.2	820	300	forest	2014-2017	[36]
IT-BCi	15.0	40.5	CRO	18	600	15	crop	2017	[37]
IT-Cp2	12.4	41.7	EBF	15.2	805	6	forest	2013-2017	[38]
IT-Lsn	12.8	45.7	OSH	13.1	1083	1	crop	2017-2017	[39]
IT-SR2	10.3	43.7	ENF	14.2	920	4	forest	2014-2017	[40]
IT-Tor	7.6	45.8	GRA	2.9	920	2160	grass	2009-2017	[41]
NL-Loo	5.7	52.2	ENF	9.8	786	25	forest	2004-2017	[42]
RU-Fy2	32.9	56.4	ENF	3.9	711	265	forest	2016-2017	[43]
RU-Fyo	32.9	56.5	ENF	3.9	711	265	forest	2016-2017	[44]
SE-Deg	19.6	64.2	WET	1.2	523	270	peatland	2015-2017	[45]
SE-Htm	13.4	56.1	ENF	7.4	707	115	forest	2016-2017	[46]
SE-Nor	17.5	60.1	ENF	5.5	527	46	forest	2014-2017	[47]
SE-Ros	19.7	64.2	ENF	1.8	614	160	forest	2015-2017	[48]
SE-Svb	19.8	64.3	ENF	1.8	614	270	forest	2015-2016	[49]

(a) Data processing methods

An overview of sites is given in table S1. Raw data measured at 10 or 20 s^{-1} were processed towards half-hourly fluxes by each single site operator. Data gaps in fluxes and meteorological time series were filled, and *GPP* estimated, according to [50-55]. For sites where raw fluxes were directly provided within this study, these steps were performed by the authors, including a neighbour-based gap-filling of meteorological data between close sites [54]. For most sites, provided through the European Fluxes database cluster (http://www.europe-fluxdata.eu/), processing was performed by the Ecosystem Thematic Centre of ICOS RI and the intermediate result published [56]. Due to a slightly better performance on longer gaps than the marginal distribution sampling method implemented in [55], gaps in λET were filled by regression through the origin against ET_0, using an adaptive window as described in [53]. Subsequently the remaining available energy according to ET_0 was used in the same way to fill gaps in H. A site was used if after these steps turbulent fluxes of sensible and latent heat and CO_2 as well as incoming solar radiation, air temperature, humidity and precipitation were available for at least 80% of the period April to September and at least 60% of the full year, both for 2018 and at least one year in the period from 2004 to 2017. Data of the available years from this period were averaged to serve as a reference, with an additional constraint of omitting years with incomparable land use conditions (e.g. different crops in a crop rotation, or the years before wood harvesting). Remaining gaps in final variables required as an unbiased annual budget were filled by first applying reduced major axis [57] regression between the daily time series of 2018 and the reference year and finally, if required, linear regression. Statistics that do not require gapless annual budgets, but a list of jointly available variables, such as energy balance closure EBC [58], were computed without this step after list-wise deletion of input records with missing data. In Eq. (2.2), due to varying data availability between sites, we used site-specific values of d and h_m, but a global estimate of 1.42 10^6 J m^{-3} K^{-1} for $\rho_s c_s$. T_c was in most cases approximated by T_a; $m_c\ A^{-1}$ was either known for a site or approximated from canopy height h_c via regression on all sites with known h_c and $m_c\ A^{-1}$. Grass reference evapotranspiration according to [59] was computed using the hourly version with solar incoming radiation (R_{si}). The sum parameter of growing-degree days was computed by cumulatively adding all mean daily temperatures above 10°C per year.

To estimate confidence intervals of changes in fluxes and state variables across groups of sites (i.e. *affected* ecosystems or the group of all *affected* vs. all *other* sites), we considered both, the inter-annual variability between multiple reference years at each site, and the spatial variability between sites in the same group. Systematic measurement errors were not included given that they likely affect all years similarly, in line with [60], which is explicitly shown for the energy balance closure gap in the following section. Random errors in half-hourly measurements [61] strongly decrease in relative importance during propagation into annual sums [60]. For those sites and variables where estimates on annually aggregated random errors were available [56, 62], these were considerably smaller than the measured inter-annual variability, in which they are implicitly included. The mean change across a group of sites, for each of which a mean reference year was computed beforehand, is equivalent to a weighted average of differences between 2018 and each single reference year, where the weights are the inverse of the number of reference years available for the site. The corresponding confidence interval is given by

$$\mathrm{CI} = x \pm t_{\left(1-\frac{\alpha}{2};N_{eff}-1\right)}\sqrt{\frac{\overline{s_{ia}{}^2}+s_{sp}{}^2}{N_{eff}-1}}, \qquad \text{(Eq. S1)}$$

where CI is the two-sided confidence interval of the change x at error probability α (0.05 for the 95% confidence), t student's t distribution, $s_{ia}{}^2$ the biased (uncorrected) inter-annual variance among reference years at each site, $s_{sp}{}^2$ the biased spatial variance of mean changes between the sites of the group, and the overbar denotes averaging. Note that the root term is the standard error and its product with $\sqrt{N_{eff}}$ the unbiased standard deviation. N_{eff} is the effective sample size of a weighted variance [63], which is in our case exactly equivalent to

$$N_{eff} = \frac{1}{\left(\frac{1}{N_{\iota a}}\right)} \cdot N_{sp}. \qquad \text{(Eq. S2)}$$

The first factor is the harmonic mean of the number of reference years available at the sites in the group, the second the number of sites. Confidence intervals not including zero indicate a significant change. Mean and relative changes, their confidence interval, and number of sites with available measurements of the respective variable are given in table S2. The same approach is used in figure S2 to estimate confidence intervals from the combined variances between days in a rolling window, reference years and sites. In this case, the number of days in the rolling window contributing to N_{eff} could lead to erroneously narrow confidence intervals due to correlation (dependence) between consecutive days. Following autocorrelation analyses of daily flux data, we thus reduced the number of days contributing to N_{eff} by a factor of four days to arrive at conservative confidence interval estimates.

Table S2: Overview of absolute and relative changes of discussed variables in 2018 vs. reference period. CI is the 95% confidence interval of the change (Eq. S1 and S2), both change and CI in units given to the left. Number of sites is N_{sp} entering Eq. S2.

		affected	***affected*** **crop**	***affected*** **forest**	***affected*** **grass**	***affected*** **peat**	***other***
P (mm)	change	**-180**	**-125**	**-207**	**-169**	**-140**	**+100**
	CI	±28	±74	±39	±68	±58	±83
	relative	**-22.9%**	**-15.8%**	**-27.3%**	**-16.9%**	**-21.4%**	**13.6%**
	sites	46	7	26	7	6	10
ET_0 (mm)	change	**+105**	**+91**	**+109**	**+103**	**+107**	**-48**
	CI	±8	±26	±12	±15	±20	±42
	relative	**16.0%**	**12.6%**	**17.1%**	**14.4%**	**17.8%**	**-4.5%**
	sites	46	7	26	7	6	10
T_{air} (°C)	change	**+0.82**	**+0.92**	**+0.80**	**+0.93**	**+0.66**	+0.05
	CI	±0.13	±0.43	±0.17	±0.17	±0.55	±0.32
	sites	46	7	26	7	6	10
R_g (MJ m^{-2} yr^{-1})	change	**+360**	**+307**	**+357**	**+353**	**+442**	**-147**
	CI	±32	±84	±45	±51	±96	±95
	relative	**9.2%**	**7.4%**	**9.5%**	**8.3%**	**11.9%**	**-2.7%**
	sites	46	7	26	7	6	10
SW_{out} (MJ m^{-2} yr^{-1})	change	**+69**	+32	**+49**	**+103**	**+148**	-29
	CI	±21	±62	±15	±63	±123	±67
	relative	**11.5%**	4.0%	**11.8%**	**10.5%**	**25.3%**	-2.6%
	sites	35	5	20	5	5	7
albedo	change	+0.004	-0.007	+0.002	+0.003	+0.020	+0.001
	CI	±0.005	±0.014	±0.004	±0.015	±0.026	±0.014
	relative	2.3%	-3.4%	2.0%	1.2%	12.1%	0.2%
	sites	35	5	20	5	5	7
LW_{in} (MJ m^{-2} yr^{-1})	change	+24	**+87**	+32	-29	-17	**+155**
	CI	±30	±77	±37	±52	±148	±73
	relative	0.2%	0.9%	0.3%	-0.3%	-0.2%	1.6%
	sites	44	6	26	7	5	10
LW_{out} (MJ m^{-2} yr^{-1})	change	**+148**	**+227**	**+153**	**+169**	+33	-6
	CI	±29	±85	±25	±48	±204	±106
	relative	**1.3%**	**2.0%**	**1.4%**	**1.5%**	0.3%	0.0%
	sites	35	5	20	5	5	6
R_n (MJ m^{-2} yr^{-1})	change	**+123**	**+141**	+98	**+140**	**+177**	+16
	CI	±60	±87	±100	±80	±126	±53
	relative	**6.3%**	**7.8%**	4.7%	**7.9%**	**9.6%**	0.6%
	sites	36	5	20	5	6	7

Table S2 continued

		affected	*affected crop*	*affected forest*	*affected grass*	*affected peat*	*other*
EBC (filled)	change	**+0.02**	-0.02	**+0.04**	+0.00	+0.04	+0.04
	CI	±0.02	±0.05	±0.03	±0.03	±0.07	±0.13
	relative	**3.0%**	-2.7%	**4.9%**	-0.6%	5.2%	4.9%
	sites	45	7	25	7	6	9
H (MJ m^{-2} yr^{-1})	change	**+169**	**+135**	**+235**	**+79**	+30	-34
	CI	±36	±97	±52	±33	±58	±120
	relative	**32.3%**	**43.5%**	**34.2%**	**28.9%**	8.2%	-3.2%
	sites	46	7	26	7	6	10
λET (MJ m^{-2} yr^{-1})	change	0	**-122**	-29	+54	**+205**	-9
	CI	±39	±118	±49	±68	±94	±123
	relative	0.0%	**-10.2%**	-2.8%	4.4%	**20.8%**	-0.7%
	sites	46	7	26	7	6	10
$\lambda ET\ (H+\lambda ET)^{-1}$	change	**-0.07**	**-0.10**	**-0.09**	**-0.05**	+0.03	+0.03
	CI	±0.02	±0.08	±0.03	±0.04	±0.05	±0.04
	relative	**-10.5%**	**-12.4%**	**-14.5%**	**-5.8%**	3.3%	5.3%
	sites	44	7	26	6	5	10
S_l (MJ m^{-2} yr^{-1})	change	**+9.3**	**+33.4**	**+4.8**	**+17.0**	-7.8	-6.8
	CI	±4.6	±26.1	±2.6	±9.6	±13.5	±17.3
	relative	**299.2%**	**1384.2%**	**256.8%**	**110.4%**	-156.9%	-63.8%
	sites	46	7	26	7	6	10
E_c (MJ m^{-2} yr^{-1})	change	**-1.6**	-2.1	-1.0	**-2.9**	-2.1	+0.4
	CI	±1.1	±5.2	±1.4	±1.9	±2.9	±3.1
	relative	**-17.8%**	-32.4%	-8.3%	**-44.0%**	-74.9%	7.5%
	sites	46	7	26	7	6	10
IWUE* (gC hPa kg^{-1} H_2O)	change	**+3.1**	**+2.8**	**+3.8**	**+2.5**	**+1.0**	+0.1
	CI	±0.5	±1.0	±0.7	±0.9	±0.7	±1.5
	relative	**31.4%**	**32.6%**	**35.3%**	**20.7%**	**21.2%**	0.4%
	sites	45	6	26	7	6	10
WUE_{eco}	change	**-0.0011**	-0.0015	-0.0002	**-0.0027**	-0.0023	+0.0004
	CI	±0.0009	±0.0043	±0.0012	±0.0013	±0.0026	±0.0021
	relative	**-13.8%**	-27.7%	-2.3%	**-48.7%**	-88.5%	9.0%
	sites	46	7	26	7	6	10
swc (cm^3 cm^{-3})	change	**-0.051**	**-0.057**	**-0.044**	**-0.073**	**-0.038**	**+0.032**
	CI	±0.010	±0.049	±0.014	±0.011	±0.034	±0.028
	relative	**-16.2%**	**-19.8%**	**-17.0%**	**-18.6%**	**-5.5%**	**15.5%**
	sites	33	5	20	6	2	9

(b) Energy balance closure

Eddy-Covariance measurements are known for a gap in the energy balance closure (EBC): the sum of H and λET is frequently about 15 to 30% smaller than R_n - S_l - E_c [58, 64]. Current theory suggests a number of different reasons including underestimation of the turbulent heat fluxes due to surface heterogeneity or incomplete correction of spectral losses, or unaccounted energy storage [64-68]. However, there is no consensus yet on the application of a correction, its distribution between H and λET and its implications for E_c [69, 70]. However, relative changes in turbulent fluxes between years remain unaffected as long as EBC does not change systematically between respective years. Figure S1 demonstrates there was little average change in EBC, with a closure gap around 20% both in the reference period and in 2018. EBC slightly improved during the drought, although both increase and decrease were found for individual sites.

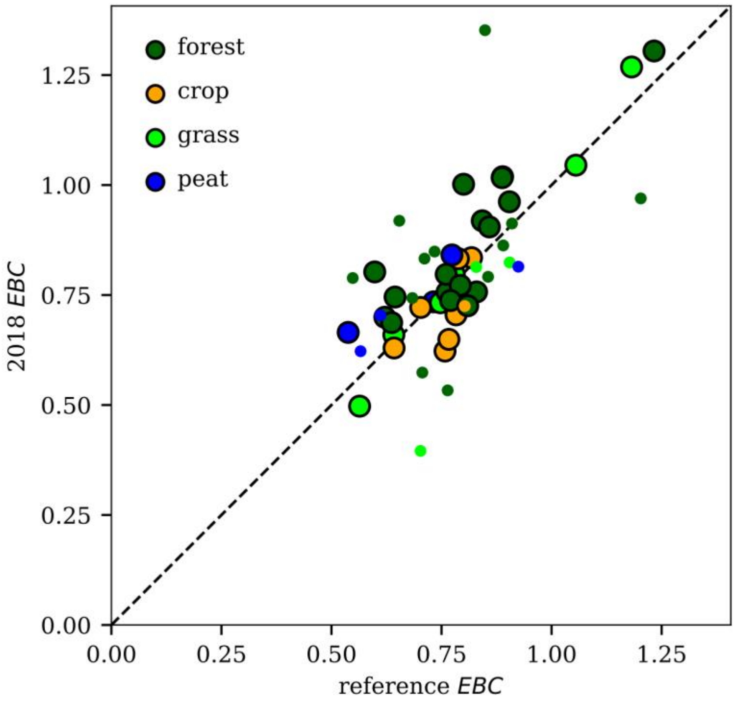

Figure S1: Energy balance closure (EBC), i.e., annual cumulative $(H+\lambda ET)(R_n\text{-}S_l\text{-}E_c)^{-1}$, compared between 2018 and the reference period for each site. Large symbols indicate sites where measurements of these variables were jointly available during both periods, small symbols indicate sites where $R_n\text{-}S_l$ was estimated from gap-filled short-wave incoming radiation according to [59]. Mean EBC across sites changed from 0.77 (reference) to 0.81 (2018) for the high-quality and from 0.77 to 0.80 for the filled records.

(c) Intra-annual temporal dynamics of *ET*

On average, grassland sites showed higher evapotranspiration losses compared to the reference period in the early stages of the drought, and lower ones later presumably caused by soil water depletion. As a result, sensible heat fluxes were particularly high compared to the reference period during late stages of the drought (figure S2). Forests showed less extreme relative changes, in accordance with [71]. However, it should also be noted that on average forests showed higher sensible heat fluxes than grasslands both during the reference period and 2018, partly because of having a lower albedo. Any mitigation strategy by land use change would need to carefully consider this drawback effect. Cropland sites showed an even stronger tendency of evapotranspiration to decline during later stages of the drought. Inspection of a single cropland site demonstrates that this effect is at least partly due to earlier maturity and harvest, and strongly reduced evaporation from the dry topsoil after harvest (figure S2).

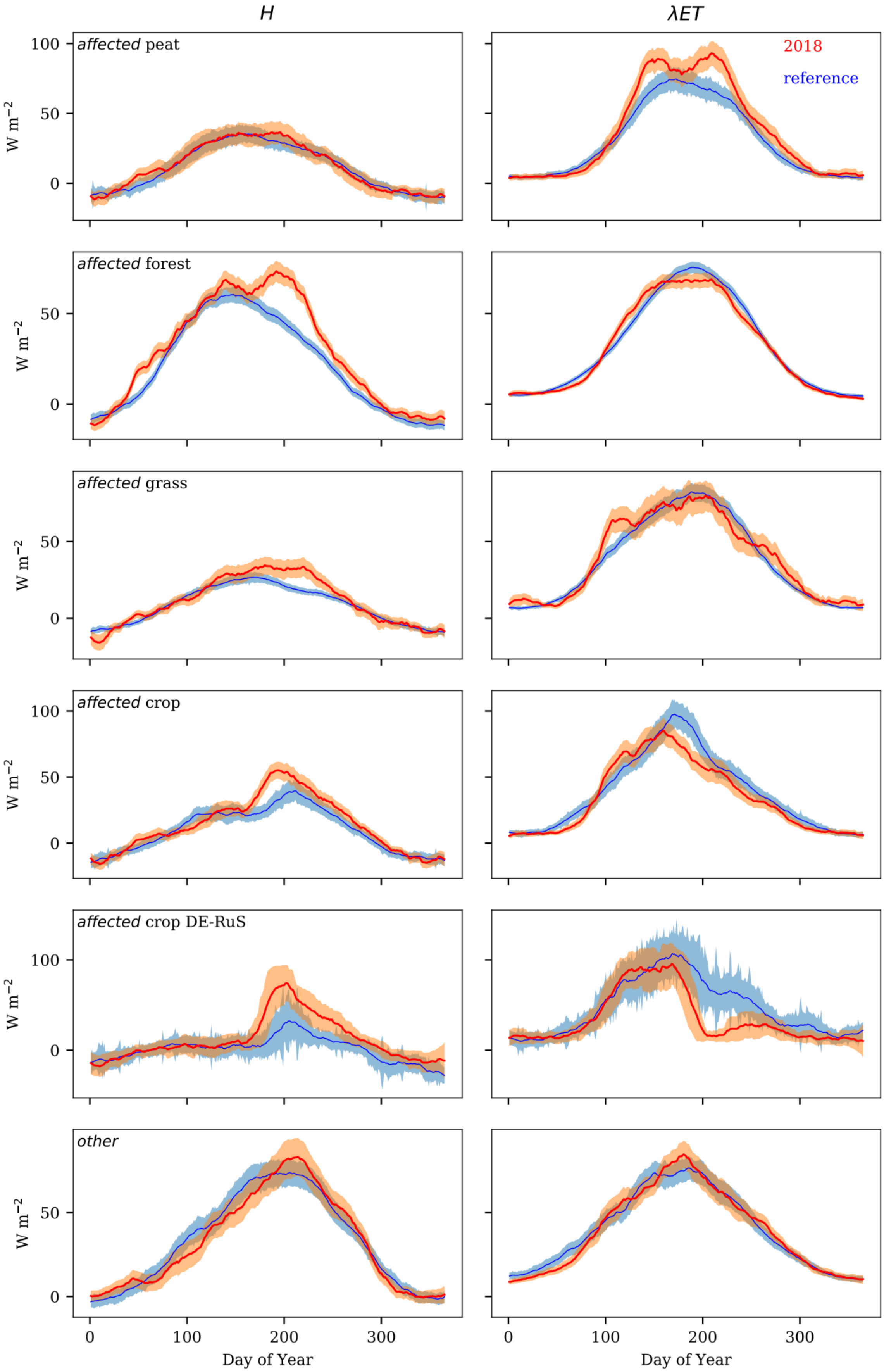

Figure S2: Annual course of sensible (*H*, left column) and latent heat flux (*λET*, right column, W m^{-2}) averaged across groups of ecosystems as a 30-day rolling average during 2018 (red) and the reference period (blue). Shaded areas indicate the 95% confidence interval estimated from variability within the 30-day rolling window, between reference years and between sites (see supplementary material (a)). Harvest of winter wheat at DE-RuS took place at Day of Year 197 in 2018, while in the two reference years it took place at Day 223 and 215, respectively.

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