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Historical variation in the normalized difference vegetation index compared with soil moisture in a taiga forest ecosystem in northeastern Siberia

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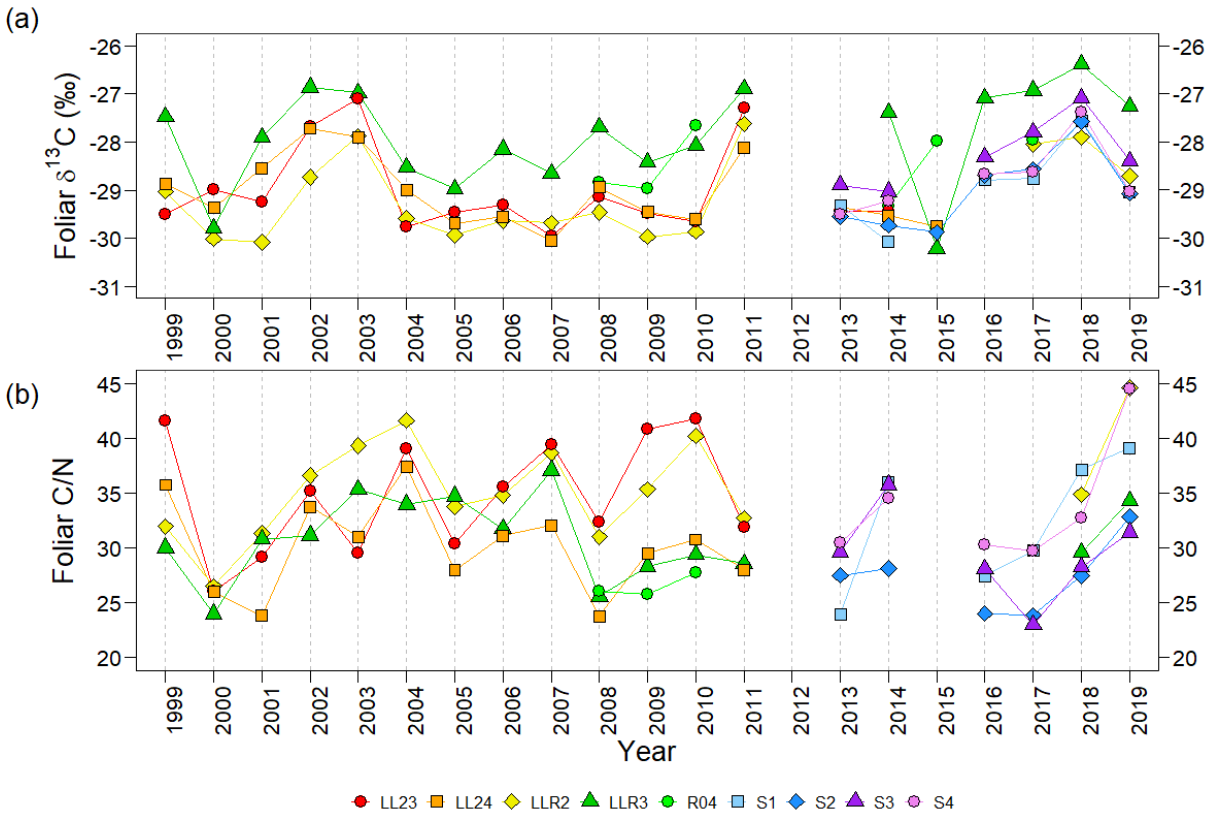

Figure S1. Temporal variations of raw data in (a) the foliar $\delta^{13}C$ and (b) C/N of nine trees in the typical forest during 1999–2019. The four trees LL23, LL24, LLR2, and LLR3 were continuously sampled from 1999 to 2011, and the tree R04 was sampled during 2008–2010, 2014, 2015, and 2017. The four trees S1, S2, S3, and S4 were sampled from 2013. The number of trees sampled for the foliar $\delta^{13}C$ (a) every year was: n = 0 in 2012; n = 4 in 1999–2007, 2011, and 2015; n = 5 in 2008–2010 and 2016; n = 6 in 2013, 2018, and 2019; n = 7 in 2017; n = 8 in 2014. The number of trees sampled for the foliar C/N (b) every year was: n = 0 in 2012 and 2015; n = 4 in 1999–2007, 2011, 2013, 2014, and 2016–2017; n = 5 in 2008–2010; n = 6 in 2018 and 2019. From each tree, four stems with current year stems were taken, and leaves on previous and two-year stems were collected in August every year. Needles of each tree were mixed well, kept in a paper bag, and oven-dried at 60 °C in the field. Samples collected before 2004 and after 2004 were brought to Kyoto University and Hokkaido University, respectively, where they were powdered with liquid nitrogen, and oven-dried again. Each sample was then wrapped in a tin capsule and analyzed for carbon and nitrogen contents and for their isotope compositions using the EA-IRMS system. All data obtained in each year were averaged to build a successive temporal variation in the foliar $\delta^{13}C$ and C/N (Fig. 3d and 3f).

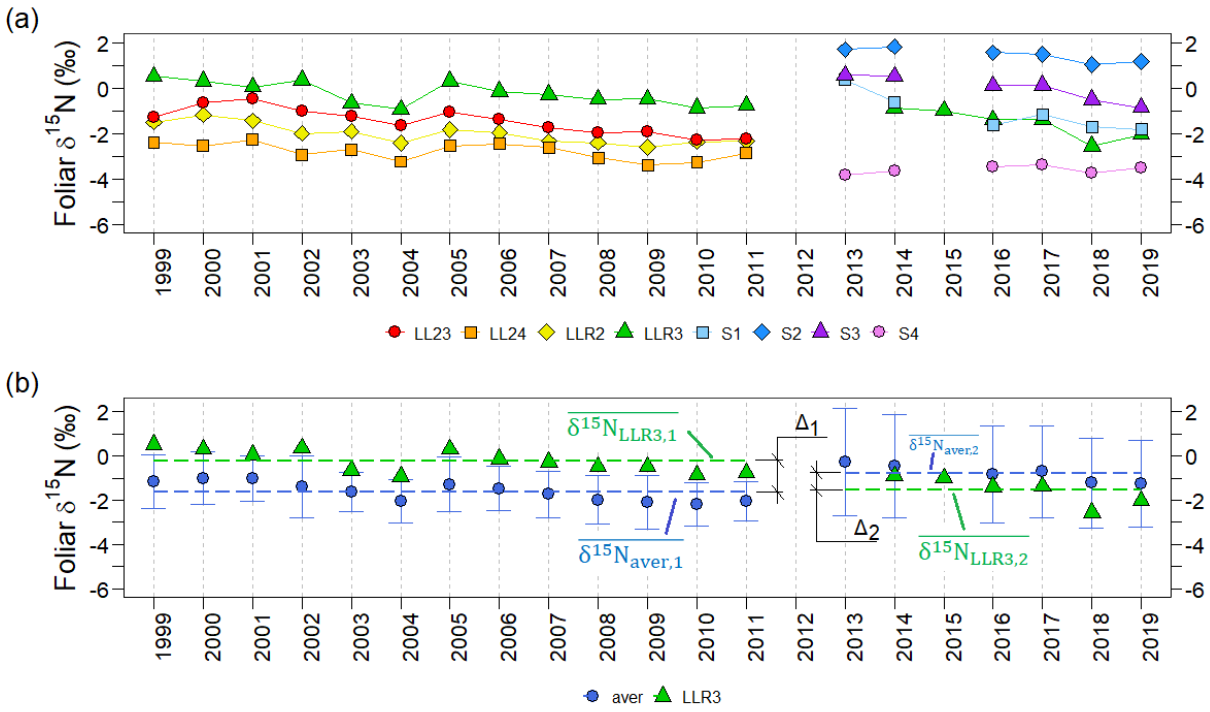

Figure S2. Temporal variations in raw data of (a) the foliar $\delta^{15}N$ of the same trees as in Fig. S2, and (b) the method of calculation to obtain successive temporal variation in the foliar $\delta^{15}N$. The $\delta^{15}N$ value differs from tree to tree because of differences in the nitrogen sources of the tree. To obtain continuous temporal variation, first, the average values from LL23, LL24, LLR2, and LLR3 during 1999–2011 ($\delta^{15}N_{aver,1}$) and S1–S4 during 2013–2019 ($\delta^{15}N_{aver,2}$) were calculated, and, second, the differences between the averages and LLR3 (Δ_1 and Δ_2, respectively) were obtained. Then, the continuous average value was calculated by adding Δ_1 and Δ_2 to $\delta^{15}N_{aver,2}$ (Fig. 3c).

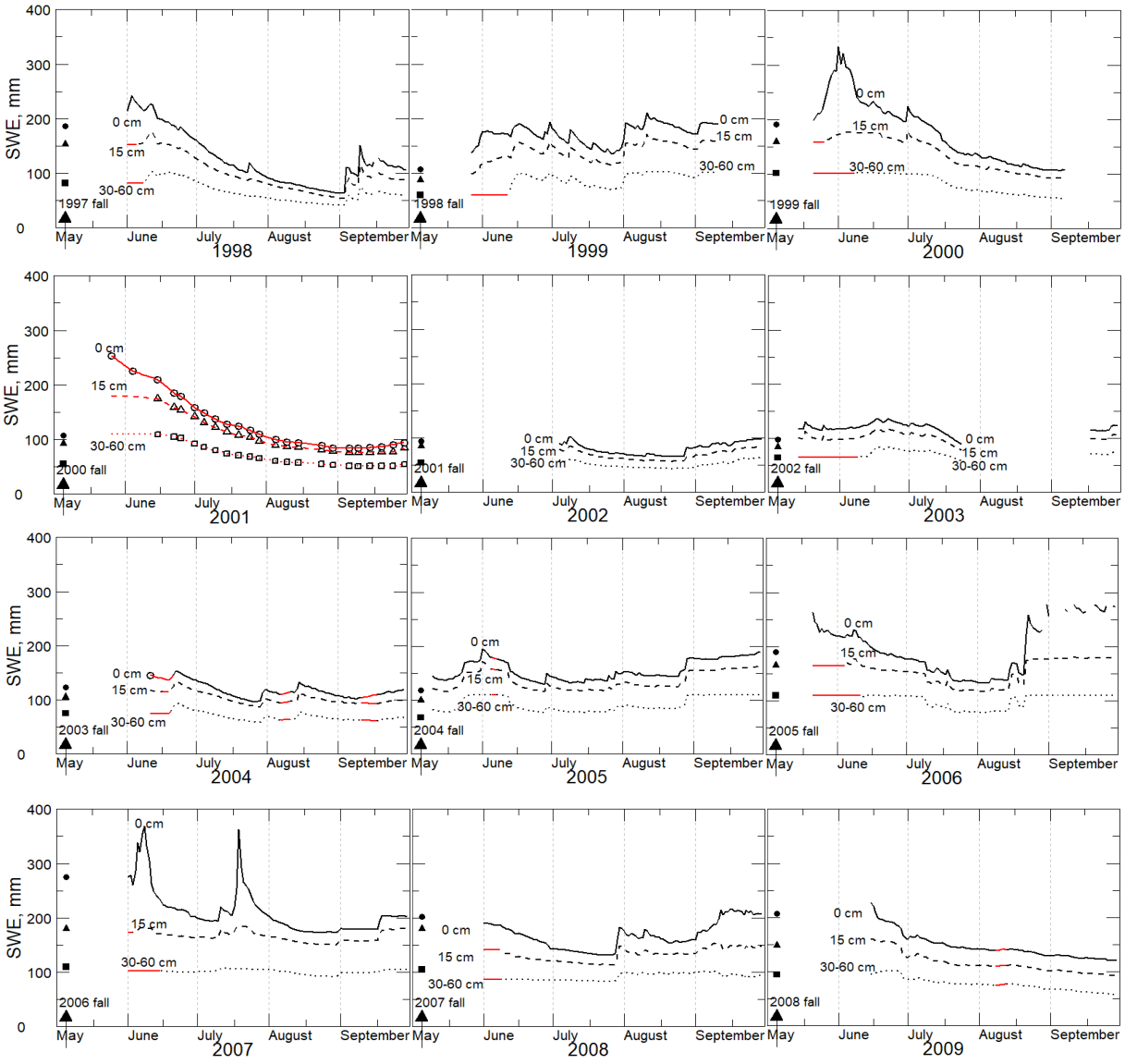

Figure S3. Daily variation in soil moisture water equivalent (SWE, mm), including ice from the surface of the mineral soil layer to 60 cm during May to September from 1998 to 2019. Cumulative SWE from a depth of 60 cm to 30 cm, 30 to 15 cm, and 15 to 0 cm are shown in the figure. Black dotted, dashed, and solid lines show continuous daily data, and open circle, triangle, and square shown in 2001 and 2004 represent one-day data (manually observed data). The filled circle, triangle, and square with an arrow in the left side of each figure represent SWE in the previous September (before the freeze). The SWE was calculated with the same or similar methods as described by Sugimoto et al. (2003), that is, from volumetric soil water content (VSWC, m^3/m^3) observed using time-domain reflectometry (TDR) by multiplying with layer thickness (mm). The SWE was estimated from regression relationships of TDR measurements between manual (Moisture Point, Environmental Sensors Inc., Canada) and automatic observations. Three automatic measurement systems were used in different years: TRIME IMKO P2 sensors (IMKO Micromodultechnik GmbH, Germany) at 10, 20, and 40 cm depths during 1998, 1999, and 2002–2008; Decagon ECH2O sensors (Meter Environment, USA) at 7.5, 22.5, and 45 cm depths during 2009, 2012, 2013, and 2016–2019; Sentek EnviroSmart (Campbell Scientific Inc, Canada) at 10, 20, 30, 40, 50, and 60 cm depths during 2010, 2014, and 2015. For 2001, SWE observed using Moisture Point is shown. Red lines show estimated values based on comparison with previously observed data.

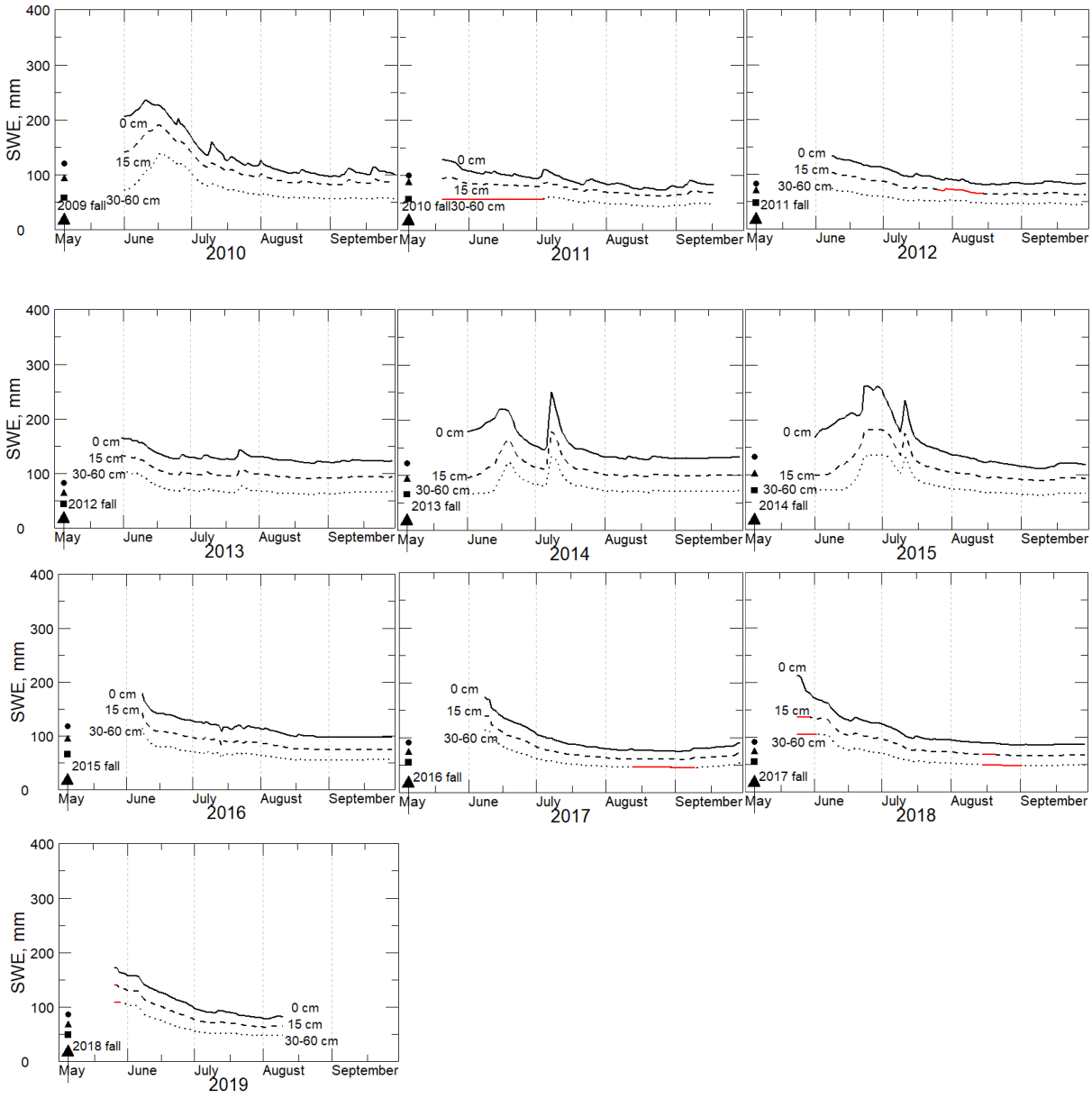

Figure S3 (continued).

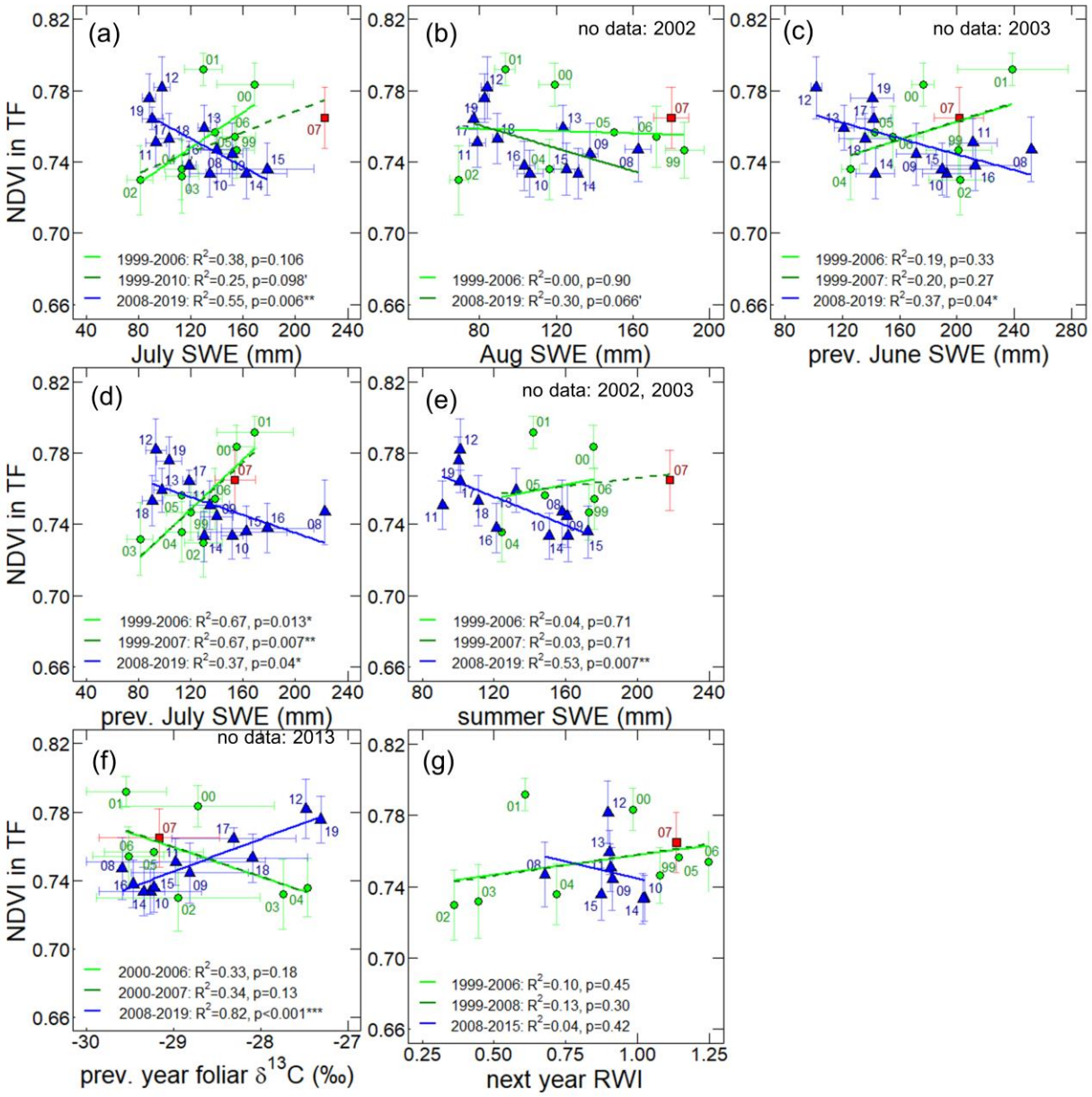

Figure S4. The relationships between the TF NDVI in the transect and ecological parameters: monthly average SWE (mm) in (a) July, (b) August, (c) previous June, (d) previous July, (e) averaged June, July, and August SWE, (f) previous year's foliar $\delta^{13}C$ (‰) during 2000–2019, (g) subsequent year's RWI during 1999–2015. Green circles and blue triangles represent the data before (1999–2006) and after (2008–2019) the wet event and red square represents the data observed in 2007. Labels nearby the data points are observation years of NDVI. Horizontal and vertical error bars represent standard deviations. Green, dark green dotted, and blue solid lines show linear regressions for 1999–2006 (before the wet event), including 2007 (the wet event), and 2008–2019 (after the wet event). In Fig. S4 (e), the dark green dotted line represents the linear regression for 1999–2010. The *p*-values and R^2 describe the significance and coefficient of determination of the regression models, respectively.

Table S1. Seasonal maximum of NDVI (mean and standards deviation) observed for four forest types (TF, RF-1, RF-2, and DF) within the transect and 10-km plot during 1999–2019. NDVI was calculated from available Landsat 5 Thematic Mapper, Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager images. All the NDVI values from Landsat 5 and 8 were converted to Landsat 7 ETM+ using the methods given by Ju and Masek (2016) and Roi et al. (2016), respectively. The value of *n* shows the number of quality plots among the 17 (TF), 11 (RF-1), 4 (RF-2), and 2 (DF) plots (total *n* = 34). The *n* for the 10-km plot shows the percentage of quality pixels among 111,556 pixels.

Satellite (transect /plot)	Year	Day of maximum NDVI		Typical forest			Regenerating forest-1			Regenerating forest-2			Damaged forest			Transect			10 km plot		
		transect	plot	aver	std	n	aver	std	n	aver	std	n	aver	std	n	aver	std	n	aver	std	n, %
L7 ETM+	1999	27.08		0.75	0.02	17	0.75	0.01	11	0.75	0.05	4	0.77	0.00	2	0.75	0.02	34	0.72	0.07	100.0
L7 ETM+	2000	13.08		0.78	0.01	17	0.79	0.02	11	0.81	0.01	4	0.80	0.00	2	0.79	0.02	34	0.80	0.05	100.0
L7 ETM+	2001	15.07		0.79	0.01	17	0.81	0.02	11	0.82	0.00	4	0.82	0.01	2	0.80	0.02	34	0.79	0.06	95.3
L7 ETM+	2002	12.08		0.73	0.02	17	0.73	0.02	11	0.73	0.01	4	0.73	0.00	2	0.73	0.02	34	0.69	0.07	100.0
L7 ETM+	2003	21.07		0.73	0.02	17	0.72	0.01	11	0.73	0.02	4	0.72	0.01	2	0.73	0.02	34	0.69	0.07	76.7
L7 ETM+	2004	17.08		0.74	0.02	17	0.75	0.03	11	0.75	0.01	4	0.73	0.02	2	0.74	0.02	34	0.70	0.08	83.1
L7 ETM+	2005	03.07		0.76		1	0.76	0.02	9	0.76	0.02	4	0.78	0.01	2	0.76	0.02	16	0.74	0.06	82.5
L7 ETM+	2006	07.08	29.07	0.75	0.02	17	0.76	0.02	11	0.78	0.03	4	0.79	0.01	2	0.76	0.02	34	0.80	0.07	76.9
L5 TM/ L7 ETM+	2007	01.07	25.07	0.76	0.02	17	0.72	0.03	11	0.68	0.02	4	0.67	0.02	2	0.73	0.04	34	0.73	0.08	51.6
L7 ETM+	2008	25.06		0.75	0.02	17	0.71	0.02	11	0.68	0.03	4	0.66	0.01	2	0.72	0.03	34	0.72	0.08	79.3
L7 ETM+	2009	14.07		0.74	0.02	16	0.71	0.00	2			0			0	0.74	0.02	18	0.73	0.06	67.7
L7 ETM+/ L5 TM	2010	01.07	16.07	0.73	0.01	17	0.71	0.01	7	0.72		1			0	0.73	0.02	25	0.72	0.06	97.9
L7 ETM+	2011	05.08	12.08	0.75	0.01	12	0.72	0.02	11	0.72	0.01	4	0.71	0.01	2	0.73	0.02	29	0.73	0.06	78.2
L7 ETM+	2012	06.07		0.78	0.02	12	0.76	0.01	11	0.75	0.02	4	0.75	0.00	2	0.77	0.02	29	0.75	0.06	81.8
L8 OLI	2013	24.07		0.76	0.01	17	0.74	0.01	11	0.72	0.01	4	0.71	0.00	2	0.74	0.02	34	0.74	0.05	98.8
L8 OLI	2014	27.07		0.73	0.01	17	0.72	0.02	11	0.72	0.01	4	0.71	0.00	2	0.73	0.02	34	0.73	0.05	99.7
L8 OLI/ L7 ETM+	2015	23.07	31.07	0.74	0.01	17	0.73	0.02	11	0.72	0.01	4	0.71	0.00	2	0.73	0.02	34	0.73	0.06	50.7
L8 OLI	2016	09.07		0.74	0.01	14	0.73	0.01	9	0.69	0.02	4	0.67	0.01	2	0.72	0.03	31	0.71	0.07	87.8
L7 ETM+	2017	20.07		0.76	0.01	7	0.75	0.02	9	0.72	0.01	4	0.71	0.00	2	0.75	0.02	22	0.73	0.06	83.6
L8 OLI	2018	07.08		0.75	0.01	17	0.74	0.01	11	0.72	0.01	4	0.71	0.00	2	0.74	0.02	34	0.72	0.06	100.0
L7 ETM+/ L8 OLI	2019	01.07	09.07	0.78	0.01	17	0.77	0.02	11	0.77	0.02	4	0.74	0.00	2	0.77	0.02	34	0.73	0.05	100.0

Table S2. Larch tree ring width index (RWI) of the typical forest during 1997-2016.

Year	RWI
1997	1.14
1998	1.23
1999	0.83
2000	1.08
2001	0.98
2002	0.61
2003	0.36
2004	0.45
2005	0.72
2006	1.14
2007	1.25
2008	1.14
2009	0.68
2010	0.91
2011	1.02
2012	0.91
2013	0.90
2014	0.90
2015	1.02
2016	0.87

Table S3. The results of the Kruskal-Wallis test, a non-parametric test to check differences in NDVI among four forest types (TF, RF-1, RF-2, DF), are presented as a significance level *p*-value. The differences in NDVI were significant at $p < 0.05$* (shown in bold font) and insignificant at $p > 0.05$.

Date	Kruskal-Wallis test *p* - value
1999	0.261
2000	**0.022***
2001	**0.002***
2002	0.881
2003	0.258
2004	0.312
2005	0.741
2006	0.063
2007	**<0.001***
2008	**<0.001***
2009	**0.035***
2010	**0.004***
2011	**0.003***
2012	**0.004***
2013	**<0.001***
2014	**0.013***
2015	**0.042***
2016	**0.002***
2017	**0.003***
2018	**0.002***
2019	0.185

Table S4. Comparisons of seasonal maximum NDVI averaged for each forest type among four forest types (TF, RF-1, RF-2, DF) in the years from 1999 to 2019 using pairwise Wilcoxon rank-sum test. The results of the tests are presented as their significance values (*p*-values). Bold font indicates a significant difference flagged as $*p < 0.05$.

Date	Forest types	DF	RF-1	RF-2
1999	RF-1	0.31		
	RF-2	1.00	1.00	
	TF	0.31	0.31	1.00
2000	RF-1	0.462		
	RF-2	1.000	0.275	
	TF	**0.035***	0.516	**0.024***
2001	RF-1	0.277		
	RF-2	0.800	0.207	
	TF	**0.035***	0.057	**0.002***
2002	RF-1	0.92		
	RF-2	0.92	0.92	
	TF	0.92	0.92	0.92
2003	RF-1	0.97		
	RF-2	0.80	0.53	
	TF	0.80	0.49	0.97
2004	RF-1	0.77		
	RF-2	0.40	0.95	
	TF	0.79	0.57	0.40
2005	RF-1	1.00		
	RF-2	1.00	1.00	
	TF	1.00	1.00	1.00
2006	RF-1	0.21		
	RF-2	0.53	0.34	
	TF	0.21	0.34	0.21
2007	RF-1	0.123		
	RF-2	0.267	**0.040***	
	TF	0.023	**0.00008***	**0.001***
2008	RF-1	**0.039***		
	RF-2	0.800	0.129	
	TF	**0.023***	**0.001***	**0.004***
2009	RF-1	–		
	RF-2	–	–	
	TF	–	**0.026***	–
2010	RF-1	–		
	RF-2	–	0.750	
	TF	–	**0.001***	0.667
2011	RF-1	0.615		
	RF-2	0.640	0.661	
	TF	**0.044***	**0.014***	**0.007***
2012	RF-1	0.346		
	RF-2	1.000	0.411	
	TF	**0.044***	**0.026***	**0.026***
2013	RF-1	0.031		
	RF-2	0.133	**0.012***	
	TF	**0.018***	**0.0007***	**0.002***
2014	RF-1	0.62		
	RF-2	0.64	0.75	
	TF	0.05	0.05	0.05
2015	RF-1	0.23		
	RF-2	0.23	0.34	
	TF	0.14	0.23	0.19
2016	RF-1	0.055		
	RF-2	0.267	**0.026***	
	TF	**0.026***	0.114	**0.005***
2017	RF-1	0.073		
	RF-2	0.133	**0.018***	
	TF	0.083	0.133	**0.018***
2018	RF-1	**0.040***		
	RF-2	0.533	**0.040***	
	TF	**0.035***	0.088	**0.008***
2019	RF-1	0.27		
	RF-2	0.27	1.00	
	TF	0.27	1.00	1.00

Table S5. Pearson correlation (*r*) between the TF NDVI and ecosystem (or climatic) parameters with 0-,1-, and 2-year time lag of the TF NDVI before the wet event (1999–2006). Bold font indicates a significant correlation. Significance levels were flagged as '$p < 0.1$, *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$. The number (n) indicates the sample size in the observed years.

Ecosystem and climatic parameters in the current year (i year)				Mean transect TF NDVI in the current year (i year)			the following year (i+1 year)			two years later (i+2 year)		
	Parameter	Observation Month	unit	r	p-value	n	r	p-value	n	r	p-value	n
Needle parameters	$\delta^{13}C$		‰	-0.61	0.11	8	-0.57	0.177	7	0.13	0.8	6
	$\delta^{15}N$		‰	**0.72**	**0.043***	**8**	0.27	0.565	7	-0.18	0.727	6
	C/N		‰	**-0.85**	**0.007****	**8**	-0.24	0.604	7	0.59	0.216	6
Soil moisture water equivalent (SWE)	June SWE	June	mm	**0.83**	**0.020***	**7**	0.43	0.333	7	-0.30	0.567	6
	July SWE	July	mm	0.61	0.106	8	**0.82**	**0.013***	**8**	0.13	0.775	7
	Aug SWE	August	mm	-0.06	0.901	7	**0.69**	**0.089'**	**7**	0.48	0.333	6
	summer SWE	JJA	mm	0.20	0.711	6	**0.79**	**0.060'**	**6**	-0.03	0.962	5
Tree-ring width index	RWI			**0.76**	**0.030***	**8**	0.30	0.464	8	0.06	0.893	8
Precipitation	Jan prec	January	mm	-0.53	0.177	8	0.01	0.973	8	0.34	0.408	8
	Feb prec	February	mm	-0.43	0.293	8	-0.19	0.66	8	0.30	0.473	8
	Mar prec	March	mm	-0.60	0.118	8	**-0.66**	**0.072'**	**8**	0.04	0.933	8
	Apr prec	April	mm	0.59	0.124	8	0.30	0.472	8	0.33	0.432	8
	May prec	May	mm	0.56	0.151	8	-0.06	0.896	8	-0.40	0.321	8
	June prec	June	mm	0.26	0.534	8	**0.75**	**0.033***	**8**	0.23	0.59	8
	July prec	July	mm	-0.61	0.109	8	-0.10	0.811	8	0.15	0.728	8
	Aug prec	August	mm	-0.14	0.739	8	0.27	0.522	8	0.42	0.297	8
	Sep prec	September	mm	-0.37	0.373	8	-0.13	0.765	8	**0.62**	**0.099'**	**8**
	Oct prec	October	mm	-0.02	0.956	8	0.42	0.298	8	**0.91**	**0.002****	**8**
	Nov prec	November	mm	-0.02	0.965	8	-0.10	0.809	8	0.04	0.916	8
	Dec prec	December	mm	-0.23	0.583	8	-0.11	0.797	8	0.34	0.41	8
	snow before summer	previous Oct - current Apr	mm	-0.05	0.899	8	0.47	0.243	8	0.18	0.662	8
	rain	MJJAS	mm	-0.31	0.452	8	0.21	0.619	8	0.52	0.187	8
	summer (JJA) rain	JJA	mm	-0.38	0.358	8	0.32	0.438	8	0.33	0.421	8
Air temperature	Jan temp	January	ºC	-0.07	0.874	8	0.57	0.142	8	0.29	0.494	8
	Feb temp	February	ºC	-0.40	0.322	8	-0.02	0.97	8	0.11	0.802	8
	Mar temp	March	ºC	-0.24	0.568	8	**-0.67**	**0.071'**	8	-0.50	0.212	8
	Apr temp	April	ºC	-0.22	0.6	8	0.20	0.637	8	-0.42	0.301	8
	May temp	May	ºC	0.49	0.215	8	0.18	0.672	8	-0.52	0.19	8
	June temp	June	ºC	0.12	0.776	8	-0.09	0.828	8	0.30	0.465	8
	July temp	July	ºC	0.30	0.466	8	-0.57	0.144	8	0.11	0.798	8
	Aug temp	August	ºC	-0.25	0.547	8	-0.54	0.171	8	-0.03	0.939	8
	Sep temp	September	ºC	-0.62	0.103	8	0.07	0.873	8	0.28	0.501	8
	Oct temp	October	ºC	-0.11	0.794	8	**-0.67**	**0.070'**	8	-0.16	0.705	8
	Nov temp	November	ºC	-0.02	0.958	8	-0.45	0.266	8	-0.38	0.347	8
	Dec temp	December	ºC	0.17	0.684	8	-0.03	0.938	8	0.24	0.573	8
	summer (JJA) temp	JJA	ºC	0.12	0.775	8	-0.48	0.228	8	0.18	0.672	8
	MJJAS temp	MJJAS	ºC	-0.04	0.926	8	-0.45	0.262	8	0.09	0.838	8

Table S6. Pearson correlation (*r*) between the TF NDVI and ecosystem (or climatic) parameters with 0-,1- and 2-year time lag of the TF NDVI after the wet event (2008-2019). Bold font indicates a significant correlation. Significance levels were flagged as the following: '$p < 0.1$, *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$. The number (n) indicates the sample size of observed years.

Ecosystem and climatic parameters in the current year (i year)				Transect TF NDVI								
				the current year (i year)			the following year (i+1 year)			two years later (i+2 year)		
	Parameter	Observation Month	unit	r	p-value	n	r	p-value	n	r	p-value	n
Needle parameters	$\delta^{13}C$		‰	0.34	0.306	11	**0.91**	**<0.001*** **	11	0.36	0.274	11
	$\delta^{15}N$		‰	-0.46	0.176	10	-0.36	0.311	10	-0.24	0.505	10
	C/N		‰	0.09	0.807	10	-0.12	0.733	10	-0.02	0.961	10
Soil water equivalent (SWE)	June SWE	June	mm	**-0.71**	**0.009****	**12**	**-0.61**	**0.036***	**12**	0.08	0.794	12
	July SWE	July	mm	**-0.74**	**0.006***	**12**	**-0.61**	**0.036***	**12**	-0.19	0.553	12
	Aug SWE	August	mm	**-0.55**	**0.066'**	**12**	**-0.64**	**0.026***	**12**	-0.43	0.159	12
	summer SWE	JJA	mm	**-0.73**	**0.008****	**12**	**-0.65**	**0.023***	**12**	-0.17	0.598	12
Tree-ring width index	RWI			-0.01	0.990	9	0.19	0.597	10	-0.13	0.710	11
Precipitation	Jan prec	January	mm	0.30	0.341	12	0.22	0.483	12	-0.17	0.587	12
	Feb prec	February	mm	0.30	0.341	12	0.05	0.887	12	-0.10	0.767	12
	Mar prec	March	mm	-0.20	0.538	12	-0.28	0.380	12	-0.26	0.413	12
	Apr prec	April	mm	0.19	0.560	12	0.18	0.582	12	0.16	0.627	12
	May prec	May	mm	-0.01	0.974	12	-0.41	0.187	12	0.27	0.401	12
	June prec	June	mm	-0.24	0.458	12	-0.12	0.699	12	0.05	0.877	12
	July prec	July	mm	-0.41	0.182	12	-0.15	0.648	12	-0.48	0.115	12
	Aug prec	August	mm	0.40	0.199	12	**0.57**	**0.053'**	12	-0.27	0.401	12
	Sep prec	September	mm	0.41	0.183	12	-0.23	0.480	12	0.06	0.865	12
	Oct prec	October	mm	0.25	0.426	12	0.14	0.667	12	0.11	0.731	12
	Nov prec	November	mm	-0.05	0.875	12	-0.23	0.479	12	-0.18	0.586	12
	Dec prec	December	mm	-0.06	0.858	12	0.41	0.187	12	0.19	0.559	12
	snow before summer	previous Oct - current Apr	mm	0.27	0.401	12	0.07	0.840	12	-0.41	0.189	12
	rain	MJJAS	mm	0.02	0.949	12	-0.14	0.663	12	-0.34	0.285	12
	summer (JJA) rain	JJA	mm	-0.18	0.566	12	0.15	0.636	12	**-0.50**	**0.097'**	**12**
Air temperature	Jan temp	January	ºC	0.22	0.500	12	0.19	0.554	12	0.38	0.221	12
	Feb temp	February	ºC	0.07	0.836	12	-0.19	0.546	12	0.17	0.597	12
	Mar temp	March	ºC	-0.21	0.519	12	0.01	0.986	12	0.27	0.396	12
	Apr temp	April	ºC	0.07	0.827	12	0.22	0.492	12	0.05	0.876	12
	May temp	May	ºC	0.10	0.748	12	0.11	0.739	12	-0.46	0.137	12
	June temp	June	ºC	**0.60**	**0.038***	**12**	-0.26	0.414	12	-0.36	0.254	12
	July temp	July	ºC	-0.12	0.710	12	0.29	0.361	12	0.31	0.334	12
	Aug temp	August	ºC	-0.07	0.824	12	0.03	0.916	12	0.34	0.283	12
	Sep temp	September	ºC	**0.52**	**0.087'**	**12**	-0.23	0.464	12	-0.18	0.574	12
	Oct temp	October	ºC	0.30	0.344	12	0.17	0.592	12	-0.30	0.335	12
	Nov temp	November	ºC	-0.30	0.345	12	0.05	0.869	12	0.19	0.547	12
	Dec temp	December	ºC	0.12	0.720	12	-0.05	0.884	12	-0.18	0.569	12
	summer (JJA) temp	JJA	ºC	0.27	0.401	12	0.05	0.878	12	0.15	0.647	12
	MJJAS temp	MJJAS	ºC	**0.50**	**0.097'**	**12**	-0.01	0.979	12	-0.13	0.679	12

Table S7. Pearson correlation (*r*) between the TF NDVI and ecosystem (or climatic) parameters with 0-,1- and 2-year time lag of the TF NDVI for the observation period of the TF NDVI (1999-2019). Bold font indicates a significant correlation. Significance levels were flagged as the following: '$p < 0.1$, *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$. The number (n) indicates the sample size of observed years.

Ecosystem and climatic parameters in the current year (i year)				Transect TF NDVI								
				the current year (i year)			the following year (i+1 year)			two years later (i+2 year)		
	Parameter	Observation Month	unit	r	p-value	n	r	p-value	n	r	p-value	n
Needle parameters	$\delta^{13}C$		‰	-0.23	0.326	20	0.17	0.495	19	0.18	0.478	18
	$\delta^{15}N$		‰	0.15	0.550	19	0.02	0.940	18	-0.13	0.613	17
	C/N		‰	-0.33	0.167	19	-0.14	0.566	18	0.27	0.291	17
Soil water equivalent (SWE)	June SWE	June	mm	0.09	0.712	20	-0.13	0.582	20	-0.06	0.791	19
	July SWE	July	mm	0.00	0.983	21	-0.04	0.872	21	-0.07	0.763	20
	Aug SWE	August	mm	-0.15	0.542	20	0.07	0.761	20	0.02	0.934	19
	summer SWE	JJA	mm	-0.14	0.569	19	-0.16	0.517	19	-0.10	0.685	18
Tree-ring width index	RWI			**0.47**	**0.047***	**18**	0.23	0.346	19	-0.07	0.785	20
Precipitation	Jan prec	January	mm	0.03	0.884	21	0.07	0.762	21	-0.02	0.928	21
	Feb prec	February	mm	-0.13	0.562	21	-0.11	0.626	21	0.13	0.587	21
	Mar prec	March	mm	-0.30	0.180	21	**-0.40**	**0.072'**	**21**	-0.13	0.574	21
	Apr prec	April	mm	0.27	0.231	21	0.11	0.649	21	0.15	0.525	21
	May prec	May	mm	0.20	0.384	21	-0.27	0.229	21	0.06	0.810	21
	June prec	June	mm	0.03	0.903	21	0.26	0.253	21	0.11	0.636	21
	July prec	July	mm	**-0.46**	**0.034***	**21**	-0.14	0.550	21	-0.10	0.662	21
	Aug prec	August	mm	0.03	0.903	21	0.35	0.120	21	-0.04	0.875	21
	Sep prec	September	mm	0.00	0.990	21	-0.11	0.631	21	0.35	0.125	21
	Oct prec	October	mm	0.13	0.587	21	0.27	0.240	21	**0.49**	**0.024***	21
	Nov prec	November	mm	-0.02	0.932	21	-0.07	0.776	21	-0.01	0.950	21
	Dec prec	December	mm	-0.16	0.492	21	0.11	0.627	21	0.25	0.284	21
	snow before summer	previous Oct - current Apr	mm	0.13	0.575	21	0.27	0.244	21	-0.10	0.675	21
	rain	MJJAS	mm	-0.16	0.494	21	0.13	0.583	21	0.13	0.575	21
	summer (JJA) rain	JJA	mm	-0.25	0.268	21	0.28	0.219	21	-0.04	0.864	21
Air temperature	Jan temp	January	ºC	0.08	0.731	21	0.19	0.407	21	0.27	0.238	21
	Feb temp	February	ºC	-0.20	0.378	21	-0.13	0.576	21	0.11	0.623	21
	Mar temp	March	ºC	-0.22	0.340	21	-0.29	0.197	21	-0.10	0.655	21
	Apr temp	April	ºC	-0.06	0.809	21	0.17	0.469	21	-0.11	0.647	21
	May temp	May	ºC	0.22	0.340	21	0.07	0.779	21	**-0.43**	**0.049***	**21**
	June temp	June	ºC	0.27	0.229	21	-0.17	0.461	21	0.01	0.975	21
	July temp	July	ºC	0.01	0.964	21	-0.13	0.560	21	0.19	0.420	21
	Aug temp	August	ºC	-0.14	0.542	21	-0.29	0.210	21	0.07	0.777	21
	Sep temp	September	ºC	-0.09	0.700	21	-0.05	0.844	21	0.10	0.676	21
	Oct temp	October	ºC	0.07	0.758	21	-0.20	0.383	21	-0.24	0.289	21
	Nov temp	November	ºC	-0.13	0.581	21	-0.24	0.292	21	-0.05	0.827	21
	Dec temp	December	ºC	0.17	0.468	21	-0.04	0.847	21	0.02	0.915	21
	summer (JJA) temp	JJA	ºC	0.09	0.684	21	-0.28	0.224	21	0.12	0.597	21
	MJJAS temp	MJJAS	ºC	0.13	0.575	21	-0.25	0.267	21	-0.03	0.880	21

Table S8. Pearson correlation (*r*) between foliar $\delta^{13}C$ and SWE in the surface layer of 0–60 cm with 0-,1- and 2-year time lag of foliar $\delta^{13}C$ for the three periods: 1999-2007, 2008-2019 and 1999-2019. Bold font indicates a significant correlation. Significance levels were shown as '$p < 0.1$, *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$. The number (n) indicates the sample size of observed years.

Period	Soil moisture water equivalent in the current year (i year)	Foliar $\delta^{13}C$								
		the current year (i year)			the following year (i+1 year)			two years later (i+2 year)		
		r	p-value	n	r	p-value	n	r	p-value	n
1999-2007	June SWE	**-0.63**	**0.093'**	**8**	0.39	0.345	8	**0.70**	**0.078'**	**7**
	July SWE	**-0.68**	**0.042***	**9**	-0.55	0.124	9	0.47	0.242	8
	Aug SWE	-0.53	0.178	8	**-0.79**	**0.020***	**8**	-0.07	0.879	7
	summer SWE	-0.33	0.476	7	-0.32	0.487	7	0.38	0.457	6
2008-2019	June SWE	**-0.74**	**0.009****	**11**	0.03	0.924	11	0.17	0.608	11
	July SWE	**-0.79**	**0.004****	**11**	-0.25	0.450	11	0.08	0.824	11
	Aug SWE	**-0.70**	**0.016***	**11**	-0.46	0.153	11	-0.04	0.901	11
	summer SWE	**-0.81**	**0.002****	**11**	-0.22	0.513	11	0.08	0.816	11
1999-2019	June SWE	**-0.71**	**<0.001*****	**19**	0.12	0.628	19	0.35	0.150	18
	July SWE	**-0.74**	**<0.001*****	**20**	-0.32	0.162	20	0.23	0.338	19
	Aug SWE	**-0.63**	**0.004****	**19**	**-0.62**	**0.004****	**19**	-0.04	0.876	18
	summer SWE	**-0.74**	**<0.001*****	**18**	-0.27	0.279	18	0.14	0.593	17

Table S9. Pearson correlation (*r*) between foliar C/N and SWE in the surface layer of 0-60 cm with 0-,1- and 2-year time lag of foliar C/N for the three periods, 1999-2006, 2008-2018 and 1999-2019. Bold font indicates a significant correlation. Significance levels were shown as 'p <0.1, *p <0.05. The sample size (n) indicates the number of observed years.

Period	Soil moisture water equivalent in the current year (i year)	Foliar C/N								
		the current year (i year)			the following year (i+1 year)			two years later (i+2 year)		
		r	p-value	n	r	p-value	n	r	p-value	n
1999-2006	June SWE	**-0.77**	**0.045***	7	-0.41	0.358	7	0.02	0.964	6
	July SWE	-0.51	0.192	8	**-0.65**	**0.082'**	**8**	-0.34	0.452	7
	Aug SWE	0.18	0.702	7	**-0.78**	**0.037***	**7**	-0.30	0.565	6
	summer SWE	-0.41	0.422	6	**-0.78**	**0.067'**	**6**	0.12	0.852	5
2008-2018 (excluding 2007 and 2019)	June SWE	**0.60**	**0.089'**	**9**	0.08	0.859	8	-0.34	0.455	7
	July SWE	0.47	0.197	9	0.04	0.927	8	-0.46	0.300	7
	Aug SWE	0.08	0.833	9	0.40	0.322	8	0.11	0.816	7
	summer SWE	0.43	0.245	9	0.19	0.660	8	-0.26	0.574	7
1999-2019	June SWE	0.04	0.888	18	-0.24	0.338	18	-0.22	0.392	17
	July SWE	0.07	0.766	19	**-0.39**	**0.100'**	**19**	-0.36	0.140	18
	Aug SWE	0.19	0.445	18	-0.24	0.341	18	-0.22	0.404	17
	summer SWE	0.18	0.491	17	-0.25	0.339	17	-0.21	0.437	16