

Supplemental material

Principal factors influencing tree growth in low-lying Mid Atlantic coastal forests (2021)

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Throughout these tables, the following abbreviations are used for study sites: Jakes Landing (JL), St. Jones (SJ), Cattus Island (CI), and Lighthouse Center (LC).

Contents

Table S1. Description and means of wind variables from 1980–2019 sourced from the Climate Engine. Standard deviations are in parenthesis. Seasons are the mean (temperature, drought) or sum (precipitation) of three-month intervals as follows: January, February, March – winter; April, May, June – spring; July, August, September – summer; and October, November, December – autumn.

Table S2. Descriptions of the study species, with their distribution temperature and precipitation ranges.

Table S3. Descriptions of tree sampling sites, including site coordinates, study species, elevation (in meters relative to North American Vertical Datum 1988 (NAVD88) and local mean higher high water (MHHW)), tree distances from the marsh edge, slope (in meters: $\Delta\text{elevation} \cdot \Delta\text{distance}^{-1}$), and forest types.

Table S4. Description and means of seasonal water levels at local and NOAA gauges from 1980–2019. Standard deviations in parenthesis. Seasons are the mean of mean higher high water (MHHW) for three-month intervals as follows: January, February, March – winter; April, May, June – spring; July, August, September – summer; and October, November, December – autumn.

Table S5. Local flood elevations and low-high group elevation cut off values in m NAVD88.

Table S6. Descriptions of NOAA and local tide gauges, as well as the statistical results for the relationship between the two gauges for each site.

Table S7. Partial least square results for factors driving differences between local and NOAA water level heights.

Table S8. Partial correlation results for site-specific mean chronologies for Jakes Landing loblolly pine (JL - PITA) and St Jones American holly (SJ – ILOP). Cell color and saturation represents the direction (positive is blue, negative is red) and strength (more saturation is stronger) of the correlation coefficient (R). Antecedent months have a ‘p’ for “previous” before the month’s abbreviation.

Table S9. Partial correlation results for site-specific mean chronologies for Cattus Island pitch pine (CI - PIRI) and Lighthouse Center American holly (LC – ILOP). Cell color and saturation represents the direction (positive is blue, negative is red) and strength (more saturation is stronger) of the correlation coefficient (R). Antecedent months have a ‘p’ for “previous” before the month’s abbreviation.

Table S10. Flood frequency estimated derived from local gauges from ~2000-2019 using the “vulntoolkit” R package (see Table 5 for the “Record Overlap,” which is the range of time used for these analyses). Data are given relative to the T_t , which is the threshold elevation used to separate high and low elevation tree groups.

Table S11. High and low elevation group tree size (from diameter at breast height or DBH) and mean chronology length (outer year-inner year) for each site. Values are given as the mean $\pm$ the group standard error. Comparisons were carried out using Student's T-test, with the t-statistic and p-value provided below if tests were significant ($\alpha=0.05$), whereas non-significant comparisons are noted with "n.s."

Table S12. Variance-covariance model results for the differences between high and low elevation chronologies. Broad evaluation tests ignore the grouping parameter (high vs. low elevation), narrow evaluation tests remove covariance (tests for lack of common signals), compound symmetry tests for group-specific variance, and unstructured tests have heterogeneous variance and covariance. Models were selected based on the lowest AIC value (grey shaded cells with italicized font). These models were created using the "dendro.varcov" function in the DendroSync package in R.

Table S13. Partial correlation results for site-specific difference of high versus low elevation tree growth for Jakes Landing loblolly pine (JL - PITA), St Jones American holly (SJ – ILOP), Cattus Island pitch pine (CI - PIRI), and Lighthouse Center American holly (LC – ILOP). Cell color and saturation represents the direction (positive is green, where high elevation trees grew more and negative is orange, where low elevation trees grew more) and strength (more saturation is stronger) of the correlation coefficient (R). Antecedent months have a 'p' for "previous" before the month's abbreviation.

Table S1. Description and means of wind variables from 1980–2019 sourced from the Climate Engine. Standard deviations are in parenthesis. Seasons are the mean (temperature, drought) or sum (precipitation) of three-month intervals as follows: January, February, March – winter; April, May, June – spring; July, August, September – summer; and October, November, December – autumn.

Site	Coordinates of Climate Engine data extraction	Season	Wind speed (m s ⁻¹)	Wind direction (degrees)
JL	39.39, -75.29	Spring	3.72 (0.59)	182 (26)
		Summer	3.42 (0.47)	186 (25)
		Autumn	4.96 (0.54)	218 (27)
		Winter	4.91 (0.56)	230 (27)
SJ	39.08, -75.44	Spring	4.21 (0.65)	182 (23)
		Summer	3.65 (0.50)	180 (28)
		Autumn	5.41 (0.59)	217 (24)
		Winter	5.60 (0.60)	228 (23)
CI	40.02, -74.07	Spring	4.23 (0.59)	192 (23)
		Summer	3.67 (0.38)	192 (24)
		Autumn	5.07 (0.45)	220 (23)
		Winter	5.30 (0.44)	233 (21)
LC	39.78, -74.11	Spring	4.74 (0.70)	194 (25)
		Summer	4.24 (0.52)	195 (23)
		Autumn	6.10 (0.66)	222 (25)
		Winter	6.32 (0.56)	236 (26)

Table S2. Descriptions of the study species, with their distribution temperature and precipitation ranges.

Species	Description	Geographic distribution ^{1,2}	Temperature range ^{1,2}	Precipitation range
Pitch pine ¹ (<i>Pinus rigida</i> Mill.) (PIRI)	monoecious, serotinous, thick-barked pine	Common in Appalachians and in pine barrens of the northern coastal plain	> -40°C to < 38°C	940-1420 mm
Loblolly pine ¹ (<i>Pinus taeda</i> L.) (PITA)	monoecious, serotinous, thick-barked pine	Common from Delaware south across southern states	> -23°C to < 38°C	1020-1520 mm
American holly ² (<i>Ilex opaca</i> Aiton) (ILOP)	evergreen and dioecious hardwood	Patchy in northern coastal plain, but common in New Jersey to southern states	> -23°C	1020-1650 mm

1. Burns RM, Honkala BH. Volume 1: Conifers. Silvics North Am. 1990. doi:10.2307/j.ctt1ffjhpb.19

2. Burns RM, Honkala BH. Volume 2: Hardwoods. Silvics North Am - Vol 2, Hardwoods. 1990;2: 148–152

Table S3. Descriptions of tree sampling sites, including site coordinates, study species, elevation (in meters relative to North American Vertical Datum 1988 (NAVD88) and local mean higher high water (MHHW)), tree distances from the marsh edge, slope (in meters: $\Delta\text{elevation} \cdot \Delta\text{distance}^{-1}$), and forest types.

Site	Coordinates (latitude, longitude)	Species	Elevation range (m)		Range of distances to marsh (m)	Slope	Forest type
			NAVD88	MHHW			
JL	39.184, -74.853	PITA	0.921 – 2.04	0.070 – 1.19	0.0 – 48	0.023	Pine-oak mix
SJ	39.089, -75.440	ILOP	0.742 – 1.63	0.015 – 0.903	2.5 – 41	0.023	Oak and beech (<i>Fagus grandifolia</i>) mix
CI	39.985, -74.122	PIRI	0.520 – 1.43	0.299 – 1.21	0.70 – 75	0.012	Pine barrens (<i>Pinus rigida</i> dominated)
LC	39.773, -74.193	ILOP	0.558 – 2.86	0.354 – 2.66	7.5 – 250	0.0095	Pine-oak mix

Table S4. Description and means of seasonal water levels at local and NOAA gauges from 1980–2019. Standard deviations in parenthesis. Seasons are the mean of mean higher high water (MHHW) for three-month intervals as follows: January, February, March – winter; April, May, June – spring; July, August, September – summer; and October, November, December – autumn.

Site	Season	Local gauge	Local water level (m)	NOAA gauge	NOAA water level (m)
JL	Spring	Sluice Creek (USGS 01411435)	0.787 (0.041)	Cape May (8536110)	1.27 (0.12)
	Summer		0.806 (0.039)		1.26 (0.14)
	Autumn		0.767 (0.059)		1.37 (0.16)
	Winter		0.720 (0.064)		1.20 (0.14)
SJ	Spring	Scotton Landing (DNERR DELSLWQ)	0.668 (0.030)	Lewes (8557380)	1.12 (0.12)
	Summer		0.704 (0.045)		1.13 (0.17)
	Autumn		0.663 (0.062)		1.22 (0.20)
	Winter		0.594 (0.065)		1.15 (0.22)
CI	Spring	Mantoloking (USGS 01408168)	0.209 (0.062)	Atlantic City (8534720)	1.13 (0.13)
	Summer		0.257 (0.039)		1.11 (0.11)
	Autumn		0.186 (0.071)		1.24 (0.18)
	Winter		0.0972 (0.071)		1.08 (0.15)
LC	Spring	Waretown (USGS 01409124)	0.180 (0.055)	Atlantic City (8534720)	1.12 (0.15)
	Summer		0.221 (0.039)		1.09 (0.11)
	Autumn		0.187 (0.095)		1.24 (0.19)
	Winter		0.0977 (0.098)		1.05 (0.14)

Table S5. Local flood elevations and low-high group elevation cut off values in m North American Vertical Datum 1988 (NAVD88).

Site	Local gage	m NAVD88				
		MHHW ¹	Maximum event ²	M _f ³	E _{min} ⁴	T _f ⁵
JL	Sluice Creek	0.851	1.83 (2012-10-30)	1.83	0.921	1.4
SJ	Scotton Landing	0.727	1.42 (2018-09-09)	1.34	0.741	1.0
CI	Mantoloking	0.221	2.10 (2012-10-30)	1.03	0.520	0.8
LC	Waretown	0.204	1.68 (2012-10-30)	1.08	0.558	0.8

1. Mean higher high water; 2. Date of occurrence in parentheses; 3. Maximum lunar high tide; 4. Equal to lowest tree elevation; 5. The threshold elevation of high versus low elevation tree groups (see Eq. 1)

Table S6. Descriptions of NOAA and local tide gauges, as well as the statistical results for the relationship between the two gauges for each site.

Site	NOAA Harmonic Gages			Local Gages		Record Overlap ⁴	R	W ⁵	m ⁶
	Gauge Name	Tide range (m)	Record Start ¹	Gage Name	Tide range (m)				
JL	Cape May	1.7	1965 (1979)	Sluice Creek ³	1.8	2003-2019	0.887	0.738	0.12
SJ	Lewes	1.4	1953 (1979)	Scotton Landing ²	1.8	2008-2019	0.749	0.668	0.11
CI	Atlantic	1.4	1911 (1975)	Mantoloking ³	0.24	2000-2019	0.560	0.677	0.17
LC	City			Waretown ³	0.37	2007-2015	0.793	0.752	0.25

1. Earliest year of record (earliest year of continuous record); 2. source: DNERR; 3. source: USGS; 4. equivalent to the total continuous length of the local gage record; 5. Kendall's W, coefficient of concordance (values of 1 are perfectly synchronous); 6. Linear regression coefficient (slope) of NOAA and local gauge.

Table S7. Partial least square results for factors driving differences between local and NOAA water level heights. Statistical output includes R², the root mean square error (RMSE), the degrees of freedom of the model (df), the number of components for the model (comps), as well as the slope coefficients (m), the standard error of the slope (se), the model t-stastic (t), and the model p-value (p).

Local gauge	NOAA gauge	Site	R ² , RMSE	df, comps	Coefficients (or m) ± se (t, p)			
					Wind speed	Wind direction	Precipitation	Temperature
Sluice	Cape May	JL	0.28, 0.04	103, 1	-0.39 ± 0.08 (-4.99, <0.01)	-0.24 ± 0.08 (-2.97, <0.01)	ns	-0.20±0.1 (-2.13, <0.05)
Scotton Landing	Lewes	SJ	0.55, 0.04	123, 3	-0.26 ± 0.09 (-2.8, <0.01)	-0.58 ± 0.08 (-7.75, <0.001)	ns	ns
Mantoloking	Atlantic City	CI	0.42, 0.06	117, 3	-0.51 ± 0.08 (-6.3, <0.001)	-0.20 ± 0.09 (-2.31, <0.05)	ns	ns
Waretown		LC	0.24, 0.06	79, 1	-0.26 ± 0.07 (-3.92, <0.001)	-0.24 ± 0.06 (-4.42, <0.001)	+0.12 ± 0.06 (2.17, <0.05)	ns

Table S8. Partial correlation results for site-specific mean chronologies for Jakes Landing loblolly pine (JL - PITA) and St Jones American holly (SJ – ILOP). Cell color and saturation represents the direction (positive is blue, negative is red) and strength (more saturation is stronger) of the correlation coefficient (*R*). Antecedent months have a ‘p’ for “previous” before the month’s abbreviation.

Site - species	Test	Variable	Month	<i>R</i>	Confidence level
JL - PITA	Drought (SPEI)~Water level	Drought (SPEI)	Jul	-0.43787	0.05
JL - PITA	Temperature~Drought (SPEI)	Drought (SPEI)	Jul	-0.41651	0.05
JL - PITA	Temperature~Drought (SPEI)	Drought (SPEI)	pDec	-0.36966	0.05
JL - PITA	Precipitation~Water level	Water level	Mar	-0.34721	0.05
JL - PITA	Temperature~Precipitation	Precipitation	Jun	-0.31322	0.05
JL - PITA	Precipitation~Water level	Precipitation	Jun	-0.31037	0.05
JL - PITA	Temperature~Precipitation	Temperature	pNov	0.27844	0.05
JL - PITA	Temperature~Water level	Temperature	Mar	0.325823	0.05
JL - PITA	Temperature~Drought (SPEI)	Temperature	Mar	0.325823	0.05
JL - PITA	Drought (SPEI)~Water level	Drought (SPEI)	May	0.397267	0.05
JL - PITA	Temperature~Precipitation	Temperature	Jan	0.416671	0.05
JL - PITA	Temperature~Water level	Temperature	Jan	0.416671	0.05
JL - PITA	Temperature~Drought (SPEI)	Temperature	Jan	0.416671	0.05
JL - PITA	Temperature~Drought (SPEI)	Drought (SPEI)	May	0.449583	0.05
JL - PITA	Temperature~Precipitation	Temperature	Feb	0.523108	0.05
JL - PITA	Temperature~Water level	Temperature	Feb	0.523108	0.05
JL - PITA	Temperature~Drought (SPEI)	Temperature	Feb	0.523108	0.05
SJ - ILOP	Drought (SPEI)~Water level	Water level	pSep	-0.41124	0.05
SJ - ILOP	Precipitation~Water level	Water level	pSep	-0.37765	0.05
SJ - ILOP	Temperature~Water level	Water level	pSep	-0.37304	0.05
SJ - ILOP	Temperature~Water level	Water level	Feb	0.310898	0.05
SJ - ILOP	Precipitation~Water level	Water level	Feb	0.347552	0.05
SJ - ILOP	Temperature~Precipitation	Precipitation	Mar	0.409529	0.05
SJ - ILOP	Drought (SPEI)~Water level	Water level	Jan	0.439615	0.05
SJ - ILOP	Precipitation~Water level	Water level	Jan	0.449642	0.05
SJ - ILOP	Temperature~Water level	Water level	Jan	0.454251	0.05

Table S9. Partial correlation results for site-specific mean chronologies for Cattus Island pitch pine (CI - PIRI) and Lighthouse Center American holly (LC – ILOP). Cell color and saturation represents the direction (positive is blue, negative is red) and strength (more saturation is stronger) of the correlation coefficient (*R*). Antecedent months have a ‘p’ for “previous” before the month’s abbreviation.

Site - species	Test	Variable	Month	<i>R</i>	Confidence level
CI - PIRI	Temperature~Precipitation	Precipitation	Jun	-0.367	0.05
CI - PIRI	Temperature~Drought (SPEI)	Drought (SPEI)	Jul	-0.360	0.05
CI - PIRI	Precipitation~Water level	Precipitation	Jun	-0.333	0.1
CI - PIRI	Precipitation~Water level	Water level	Mar	-0.31	0.1
CI - PIRI	Drought (SPEI)~Water level	Water level	pOct	-0.288	0.1
CI - PIRI	Drought (SPEI)~Water level	Water level	pNov	-0.247	0.1
CI - PIRI	Temperature~Drought (SPEI)	Drought (SPEI)	Aug	0.260	0.05
CI - PIRI	Drought (SPEI)~Water level	Drought (SPEI)	pOct	0.309	0.1
CI - PIRI	Temperature~Water level	Temperature	Mar	0.311	0.1
CI - PIRI	Temperature~Drought (SPEI)	Drought (SPEI)	pOct	0.314	0.05
CI - PIRI	Temperature~Water level	Temperature	Feb	0.345	0.1
CI - PIRI	Drought (SPEI)~Water level	Drought (SPEI)	Sep	0.353	0.1
CI - PIRI	Temperature~Drought (SPEI)	Drought (SPEI)	Sep	0.360	0.05
LC - ILOP	Temperature~Precipitation	Temperature	Sep	-0.435	0.05
LC - ILOP	Temperature~Water level	Temperature	Sep	-0.435	0.1
LC - ILOP	Temperature~Drought (SPEI)	Temperature	Sep	-0.435	0.05
LC - ILOP	Temperature~Drought (SPEI)	Drought (SPEI)	Jul	-0.409	0.05
LC - ILOP	Temperature~Precipitation	Temperature	Aug	-0.405	0.05
LC - ILOP	Temperature~Water level	Temperature	Aug	-0.405	0.1
LC - ILOP	Temperature~Drought (SPEI)	Temperature	Aug	-0.405	0.05
LC - ILOP	Temperature~Precipitation	Precipitation	pAug	-0.343	0.05
LC - ILOP	Drought (SPEI)~Water level	Drought (SPEI)	Jul	-0.324	0.1
LC - ILOP	Precipitation~Water level	Precipitation	pAug	-0.312	0.1
LC - ILOP	Precipitation~Water level	Precipitation	Jun	-0.300	0.1
LC - ILOP	Precipitation~Water level	Water level	Jun	-0.274	0.1
LC - ILOP	Drought (SPEI)~Water level	Drought (SPEI)	Aug	0.300	0.1

Table S10. Flood frequency estimates derived from local gauges from ~2000-2019 using the “vulntoolkit” R package (see Table S5 for the “Record Overlap,” which is the time range for this analysis). Data are given relative to T_f , which is the threshold elevation used to separate high and low elevation tree groups.

Site	Local gauge	Flood frequency at T_f (tides reaching T_f)	Flood duration at T_f (time at T_f)	Count of tides that surpass T_f on record	Trees sampled with high flood exposure
JL	Sluice Creek	0.015%	0.0073%	78	39%
SJ	Scotton Landing	1.3%	0.30%	1,006	27%
CI	Mantoloking	0.096%	16%	157	51%
LC	Waretown	0.20%	0.079%	451	34%

Table S11. High and low elevation group tree size (from diameter at breast height or DBH) and mean chronology length (outer year-inner year) for each site. Values are given as the mean $\pm$ the group standard error. Comparisons were carried out using Student’s T-test, with the t-statistic and p-value provided below if tests were significant ($\alpha=0.05$), whereas non-significant comparisons are noted with “n.s.”

Site	Mean DBH (cm)		<i>t, p</i>	Mean chronology length (years)		<i>t, p</i>
	High	Low		High	Low	
JL	59.5 $\pm$ 2	51.3 $\pm$ 4	2.08, 0.043	50 $\pm$ 4	62 $\pm$ 2	2.82, 0.0069
SJ	22.7 $\pm$ 1	20 $\pm$ 1	2.17, 0.034	73 $\pm$ 6	70 $\pm$ 3	n.s.
CI	44.6 $\pm$ 2	43.4 $\pm$ 1	n.s.	94 $\pm$ 8	85 $\pm$ 8	n.s.
LC	30.4 $\pm$ 1	26.8 $\pm$ 1	2.52, 0.015	103 $\pm$ 5	116 $\pm$ 5	n.s.

Table S12. Variance-covariance model results for the differences between high and low elevation chronologies. Broad evaluation tests ignore the grouping parameter (high vs. low elevation), narrow evaluation tests remove covariance (tests for lack of common signals), compound symmetry tests for group-specific variance, and unstructured tests have heterogeneous variance and covariance. Models were selected based on the lowest AIC value (grey shaded cells with italicized font). These models were created using the “dendro.varcov” function in the DendroSync package in R. Model statistics include the number of observations used in the model (n), the degree of freedom for the model (df), the model Akaike Information Criterion (AIC), the corrected AIC (AICc), and the Bayesian Information Criterion (BIC).

Site-species	Test	<i>n</i>	<i>df</i>	AIC	AICc	BIC
JL - PITA	Broad evaluation	3001	53	1468.554	1470.461	1786
	Narrow evaluation	3001	55	1528.065	1530.121	1857.491
	<i>Compound symmetry</i>	<i>3001</i>	<i>55</i>	<i>1453.054</i>	<i>1455.109</i>	<i>1782.48</i>
	Unstructured	3001	56	1454.929	1457.061	1790.345
SJ - ILOP	Broad evaluation	4296	62	7608.402	7610.218	8002.187
	Narrow evaluation	4296	64	7640.147	7642.083	8046.635
	Compound symmetry	4296	64	7575.848	7577.785	7982.336
	<i>Unstructured</i>	<i>4296</i>	<i>65</i>	<i>7575.227</i>	<i>7577.225</i>	<i>7988.066</i>
CI - PIRI	Broad evaluation	4630	53	5022.228	5023.456	5362.978
	Narrow evaluation	4630	55	5133.503	5134.826	5487.111
	<i>Compound symmetry</i>	<i>4630</i>	<i>55</i>	<i>5015.842</i>	<i>5017.165</i>	<i>5369.45</i>
	Unstructured	4630	56	5017.28	5018.652	5377.317
LC - ILOP	<i>Broad evaluation</i>	<i>5766</i>	<i>53</i>	<i>5663.572</i>	<i>5664.555</i>	<i>6016.067</i>
	Narrow evaluation	5766	55	5761.224	5762.284	6127.021
	Compound symmetry	5766	55	5664.568	5665.628	6030.365
	Unstructured	5766	56	5666.236	5667.334	6038.683

Table S13. Partial correlation results for site-specific difference of high versus low elevation tree growth for Jakes Landing loblolly pine (JL - PITA), St Jones American holly (SJ – ILOP), Cattus Island pitch pine (CI - PIRI), and Lighthouse Center American holly (LC – ILOP). Cell color and saturation represents the direction (positive is green, where high elevation trees grew more and negative is orange, where low elevation trees grew more) and strength (more saturation is stronger) of the correlation coefficient (*R*). Antecedent months have a ‘p’ for “previous” before the month’s abbreviation.

Site - species	Test	Variable	Month	<i>R</i>	Confidence level
JL - PITA	Temperature~Water level	Water level	pNov	0.295	0.05
JL - PITA	Temperature~Precipitation	Temperature	Jun	0.321	0.05
JL - PITA	Temperature~Water level	Temperature	Jun	0.321	0.05
JL - PITA	Temperature~Drought (SPEI)	Temperature	Jun	0.321	0.05
JL - PITA	Precipitation~Water level	Precipitation	pOct	0.328	0.05
JL - PITA	Temperature~Precipitation	Precipitation	pOct	0.330	0.05
JL - PITA	Drought (SPEI)~Water level	Drought (SPEI)	pDec	0.350	0.05
JL - PITA	Temperature~Drought (SPEI)	Drought (SPEI)	pDec	0.374	0.05
JL - PITA	Precipitation~Water level	Precipitation	pNov	0.432	0.05
JL - PITA	Temperature~Precipitation	Precipitation	pNov	0.433	0.05
JL - PITA	Drought (SPEI)~Water level	Drought (SPEI)	pNov	0.520	0.05
JL - PITA	Temperature~Drought (SPEI)	Drought (SPEI)	pNov	0.531	0.05
SJ - ILOP	Temperature~Drought (SPEI)	Drought (SPEI)	pDec	-0.344	0.05
SJ - ILOP	Precipitation~Water level	Water level	pSep	-0.329	0.05
SJ - ILOP	Drought (SPEI)~Water level	Drought (SPEI)	pDec	-0.315	0.05
SJ - ILOP	Temperature~Precipitation	Precipitation	pNov	-0.285	0.05
SJ - ILOP	Precipitation~Water level	Precipitation	Sep	0.424	0.05
SJ - ILOP	Temperature~Precipitation	Precipitation	Sep	0.432	0.05
CI - PIRI	Drought (SPEI)~Water level	Water level	Jan	0.420	0.05
CI - PIRI	Temperature~Water level	Water level	Jan	0.437	0.05
CI - PIRI	Drought (SPEI)~Water level	Drought (SPEI)	Aug	0.437	0.05
CI - PIRI	Precipitation~Water level	Water level	Jan	0.440	0.05
CI - PIRI	Temperature~Drought (SPEI)	Drought (SPEI)	Aug	0.454	0.05
LC - ILOP	Drought (SPEI)~Water level	Drought (SPEI)	pSep	0.313	0.05