

High Resolution Site Index Prediction in Boreal Forests Using Topographic and Wet Area Mapping Attributes

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Part I. Summary Statistics

Table S1. Summary of stand attributes for the three studied tree species.

Variables	Abbrev.	Trembling aspen (n = 97)		Lodgepole pine (n = 50)		White spruce (n = 45)	
		Mean (S.D.)	Min/Max	Mean (S.D.)	Min/Max	Mean (S.D.)	Min/Max
Site Index (m)	SI	20.97 (2.78)	14.21/25.52	14.93 (3.02)	5.44/19.43	17.40 (2.67)	11.99/22.99
Mean top height tree age (years)	AGE	45.6 (0.7)	42.3/47.0	43.4 (3.0)	33.3/47.0	83.2 (13.8)	31.7/114.3
Mean height of top height trees (m)	TH	20.0 (2.7)	13.4/24.7	13.4 (2.8)	5.1/20.2	24.3 (3.6)	11.2/29.9
Mean DBH of top height trees (cm)	DBH	20.5 (3.0)	14.1/26.7	16.2 (3.2)	8.8/23.3	38.2 (8.2)	15.2/59.0
Basal Area (m ² /ha)	BA	39.62 (11.16)	21/84	33.78 (12.91)	6/72	41.87 (11.60)	12/63
Basal Area participation (%)	BA%	94.8 (10.7)	50/100	78.2 (21.7)	23.1/100	76.9 (19.3)	42.9/100

Table S2. Summary of remotely-sensed variables considered in modeling SI by studied tree species.

Variables	Abbrev.	Trembling aspen (n = 97)		Lodgepole pine (n = 50)		White spruce (n = 45)	
		Mean (S.D.)	Min/Max	Mean (S.D.)	Min/Max	Mean (S.D.)	Min/Max
Depth-to-water at 0.5 ha c.a.(m)	DTW_0.5	4.51 (5.76)	0.02/33.17	1.00 (1.13)	0.00/5.19	1.97 (2.08)	0.02/7.11
Depth-to-water at 1 ha c.a. (m)	DTW_1	5.80 (7.65)	0.10/51.18	1.14 (1.33)	0.00/6.69	2.35 (2.47)	0.02/9.42
Depth-to-water at 2 ha c.a.(m)	DTW_2	7.47 (8.97)	0.17/55.70	1.22 (1.47)	0.00/7.50	2.67 (2.66)	0.02/10.33
Depth-to-water at 4 ha c.a. (m)	DTW_4	10.01 (10.78)	0.29/57.15	1.56 (1.85)	0.00/7.87	2.82 (2.82)	0.02/10.33
Depth-to-water at 6 ha c.a.(m)	DTW_6	11.35 (11.92)	0.36/57.26	1.86 (2.31)	0.00/8.21	3.28 (3.29)	0.03/11.78
Depth-to-water at 10 ha c.a. (m)	DTW_10	12.68 (12.57)	0.45/58.02	1.96 (2.37)	0.00/8.75	3.51 (3.33)	0.03/11.78
Flow accumulation	FA	15.7* (169.1)	3.7/1399.9	12.3* (393.2)	3.9/2515.2	42.7* (21994.9)	4.5/127651.0
Altitude (m)	ALT	810.9 (38.5)	742.8/929.8	840.6 (42.9)	755.5/908.2	802.3 (43.1)	730.7/878.3
Aspect index N-S folded	AI0	95.1 (37.5)	10.0/162.9	96.7 (34.1)	16.0/160.2	84.4 (41.5)	10.9/165.6
Aspect index NE–SW folded	AI45	88.9 (40.2)	12.6/168.2	86.0 (36.7)	18.1/161.9	72.0 (40.1)	17.8/167.5
Slope (%)	SLO	18.1 (13.5)	3.5/62.8	4.5 (9.8)	3.7/23.9	16.2 (9.0)	3.1/35.3
Mean curvature	MCUR	0.9 (1.64)	–3.09/8.93	0.64 (0.84)	–0.56/3.06	0.14 (1.25)	–2.49/3.45
Profile curvature	PRCUR	–0.59 (1.10)	–5.81/2.18	–0.39 (0.46)	–1.72/0.30	0.06 (0.84)	–1.73/2.34
Plan curvature	PLCUR	0.30 (0.68)	–1.00/3.12	0.25 (0.49)	–0.50/1.45	0.20 (0.79)	–0.87/2.95
Topographic Wetness Index	TWI	70.1* (2288.9)	16.8/ 22552.5	97.7* (2704.8)	36.6/ 18950.0	69.5* (529.5)	28.4/3619.1
Slope Position Index—15 m buffer	SPI15	Level, lower slope, middle slope, upper slope, crest		Level, middle slope, upper slope, crest		Level, lower slope, middle slope, upper slope, crest	
Slope Position Index—20 m buffer	SPI20	Depression, level, lower slope, middle slope, upper slope, crest		Level, middle slope, upper slope, crest		Level, lower slope, middle slope, upper slope, crest	

* median

Table S3. Summary of ground-measured variables considered in modeling SI by the studied tree species.

Variables	Abbrev.	Trembling aspen (n = 97)		Lodgepole pine (n = 50)		White spruce (n = 45)	
		Mean (S.D.)	Min/Max	Mean (S.D.)	Min/Max	Mean (S.D.)	Min/Max
Soil organic thickness (cm)	SOT	10.8 (5.3)	3/50	11.8 (14.0)	4/70	15.9 (10.7)	5/70
Coarse fragments (%)	CF	7.1 (13.0)	0/70	11.1 (15.2)	0/75	5.4 (12.7)	0/60
Humus form	HUM	Moder, raw moder, mor		Moder, raw moder, mor, peatymor		Moder, raw moder, mor, peatymor	
Texture	TEXT	Loamy sand, sandy loam, silt loam, loam, sandy clay loam, clay loam, silty clay loam, sandy clay, clay		Sandy loam, loam, sandy clay loam, clay loam, silty clay loam		Sandy loam, loam, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay	
Effective texture class	ETEXT	Coarse, moderately coarse, medium, fine		Moderately coarse, medium, fine		Moderately coarse, medium, fine	
Drainage	DRN	Rapidly drained, well-drained, moderately well-drained, imperfectly, poorly, very poorly		Well-drained, moderately well-drained, imperfectly, poorly, very poorly		Well-drained, moderately well-drained, imperfectly, poorly, very poorly	
Soil moisture regime	SMR	Subxeric, submesic, mesic, subhygric, hygric		Submesic, mesic, subhygric, hygric, subhydryc		Submesic, mesic, subhygric, hygric, subhydryc	
Soil nutrient regime	SNR	poor, medium, rich		Very poor, poor, medium, rich		poor, medium, rich	
Altitude (m)	ALTT	797.2 (38.2)	728.7/914.7	824.5 (42.8)	739.7/894.6	786.5 (43.5)	711.5/864.6
Aspect index N-S folded	AI0K	96.5 (49.1)	0/180	50.0 (104.0)	0/176	92.2 (50.7)	0/180
Aspect index NE-SW folded	AI45K	86.1 (52.8)	0/180	89.9 (53.7)	1/180	80.3 (56.0)	7/179
Slope (%)	SLOV	18.5 (17.6)	0/80	9.6 (6.3)	0/27	15.8 (11.9)	0/45
Slope Position	SPI	Depression, level, lower slope, middle slope, upper slope, crest		Depression, level, lower slope, middle slope, upper slope, crest		Level, lower slope, middle slope, upper slope, crest	

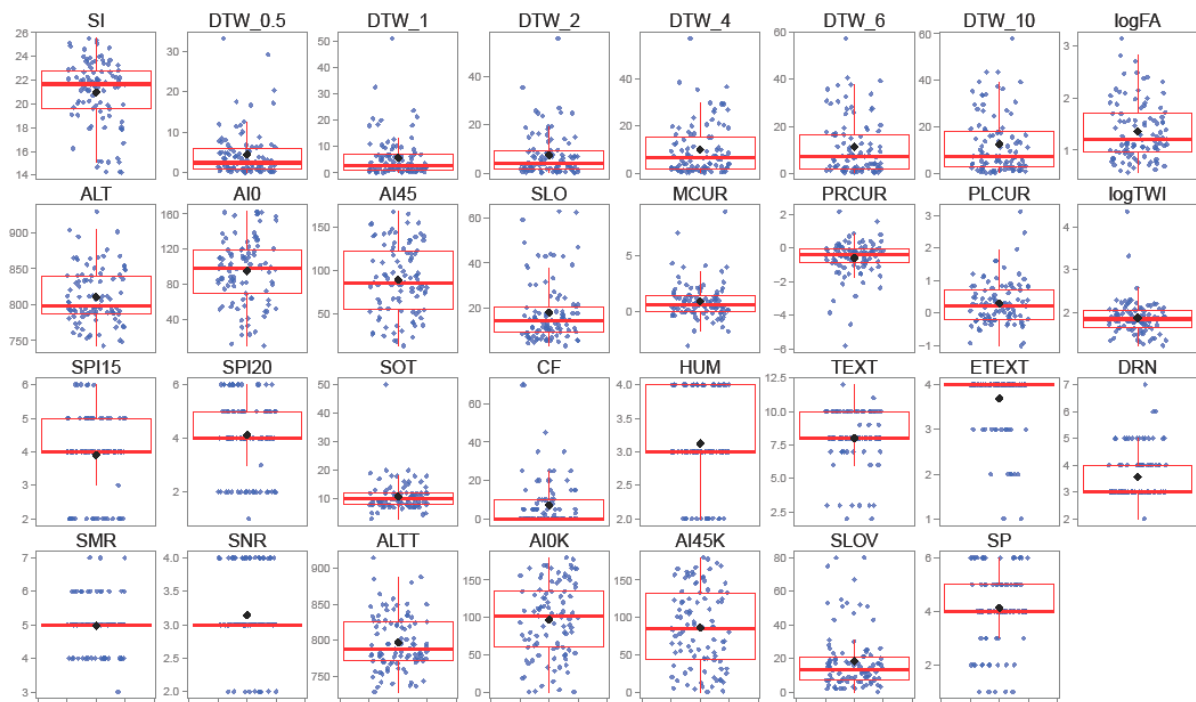


Figure S1. Box plots with jitter plots of SI and environmental (remotely-sensed and ground-based measured) variables for aspen. Black dots represent the mean.

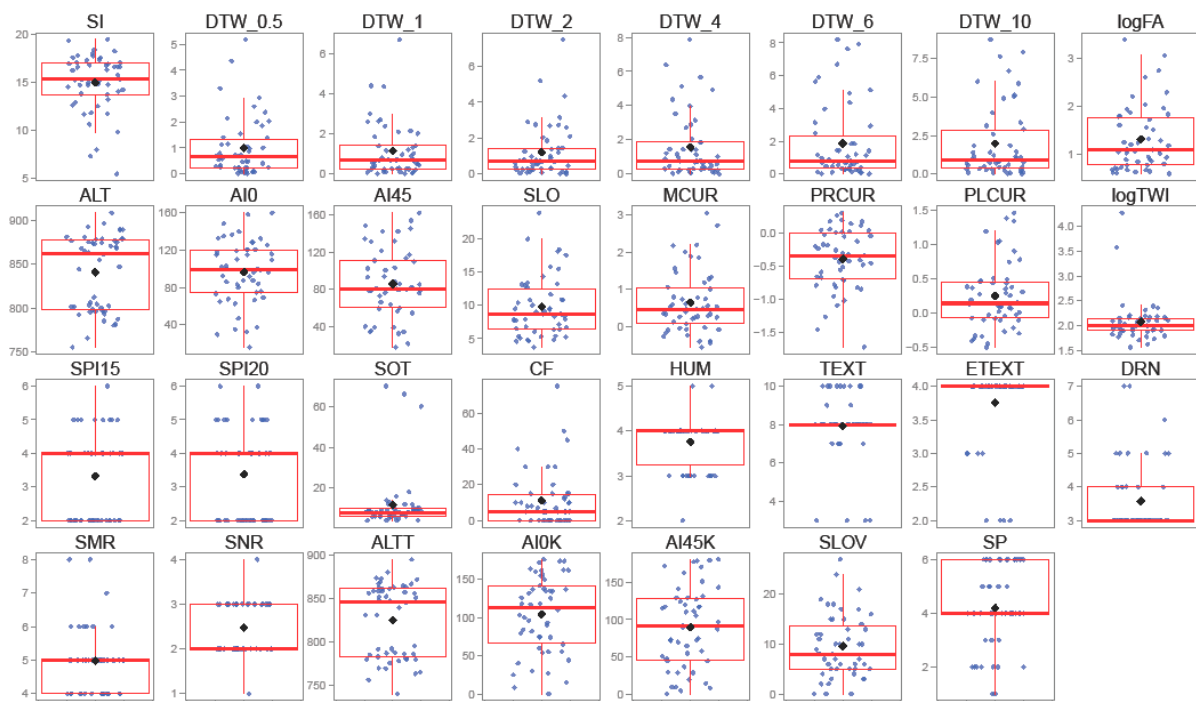


Figure S2. Box plots with jitter plots of SI and environmental (remotely-sensed and ground-based measured) variables for lodgepole pine. Black dots represent the mean.

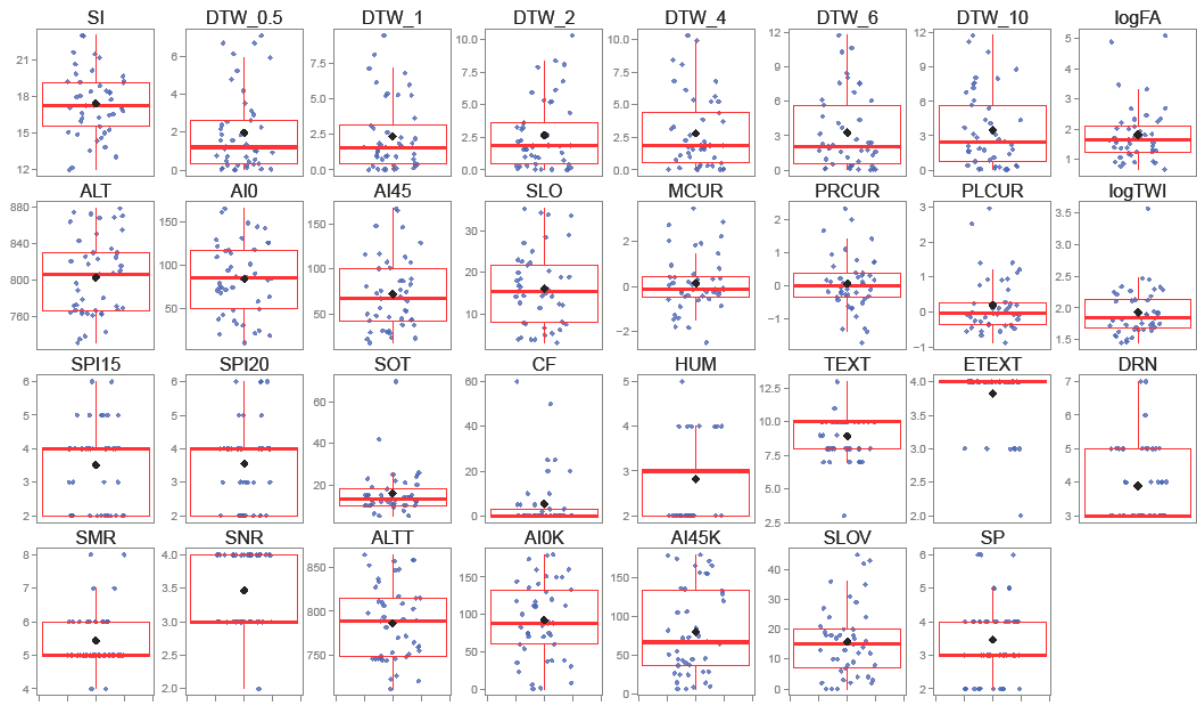


Figure S3. Box plots with jitter plots of SI and environmental (remotely-sensed and ground-based measured) variables for white spruce. Black dots represent the means.

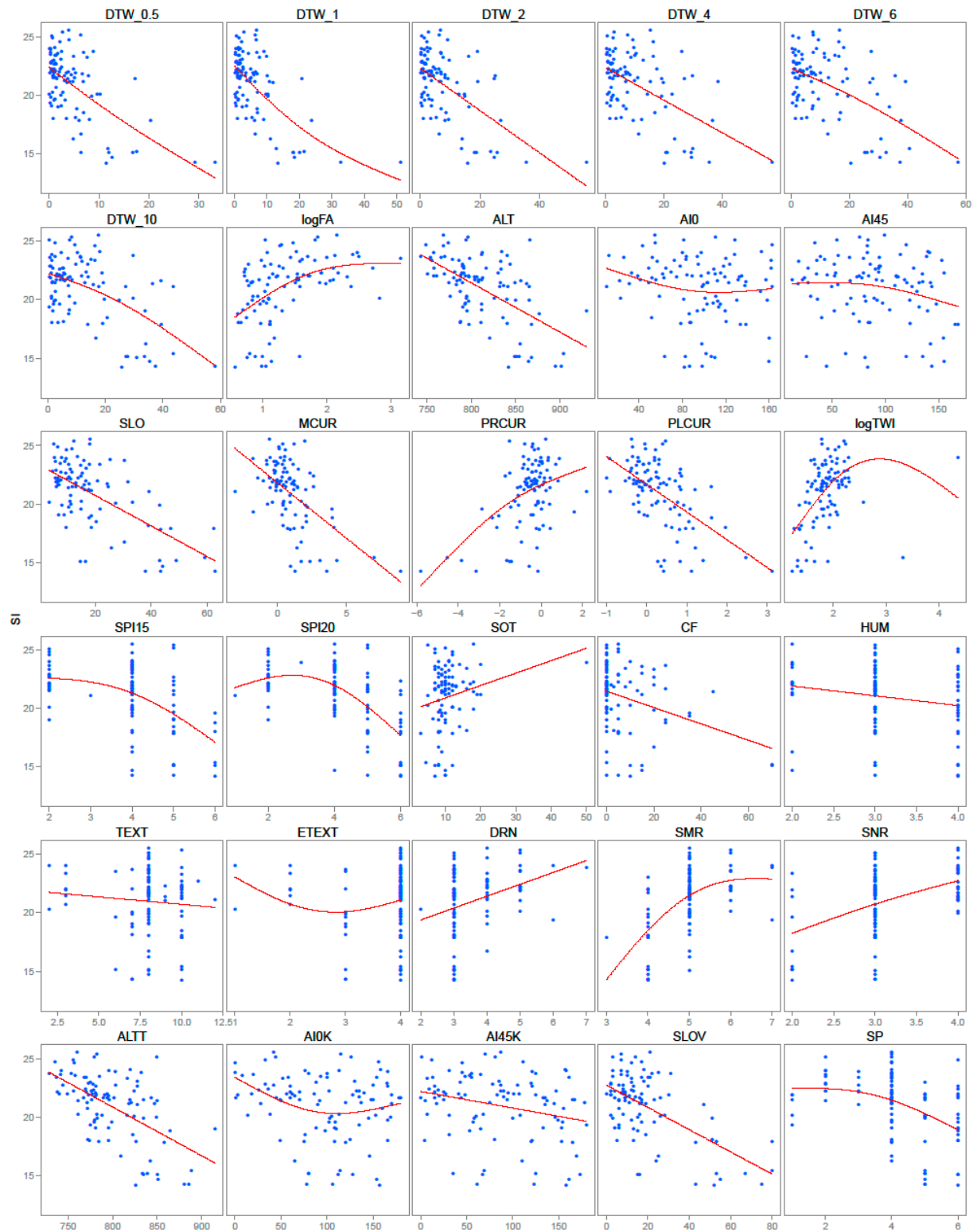


Figure S4. Scatter plots with penalized regression spline (three degrees of freedom) between environmental (remotely-sensed and ground-based measured) variables and SI for aspen.

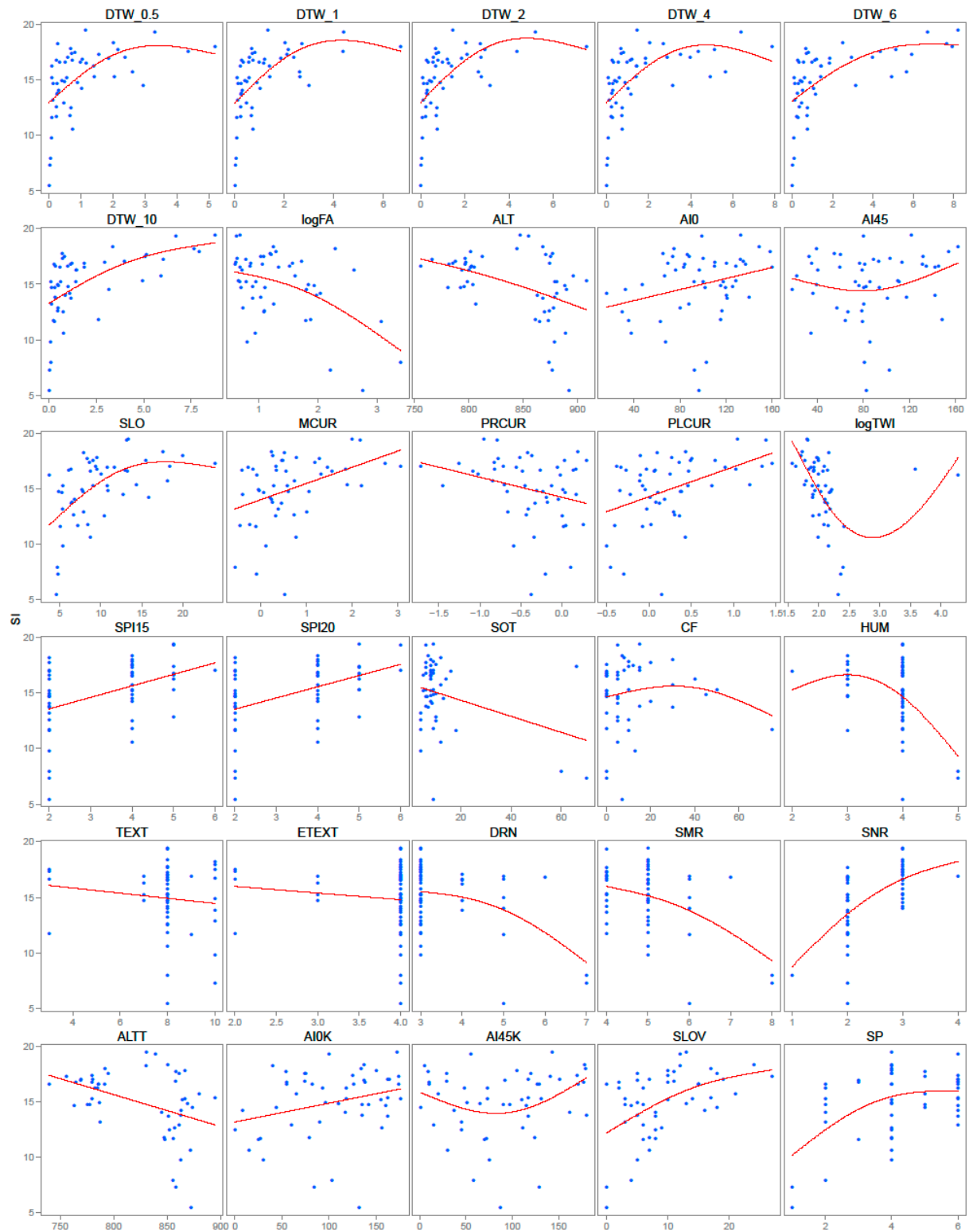


Figure S5. Scatter plots with penalized regression splines (three degrees of freedom) between environmental (remotely-sensed and ground-based measured) variables and SI for lodgepole pine.

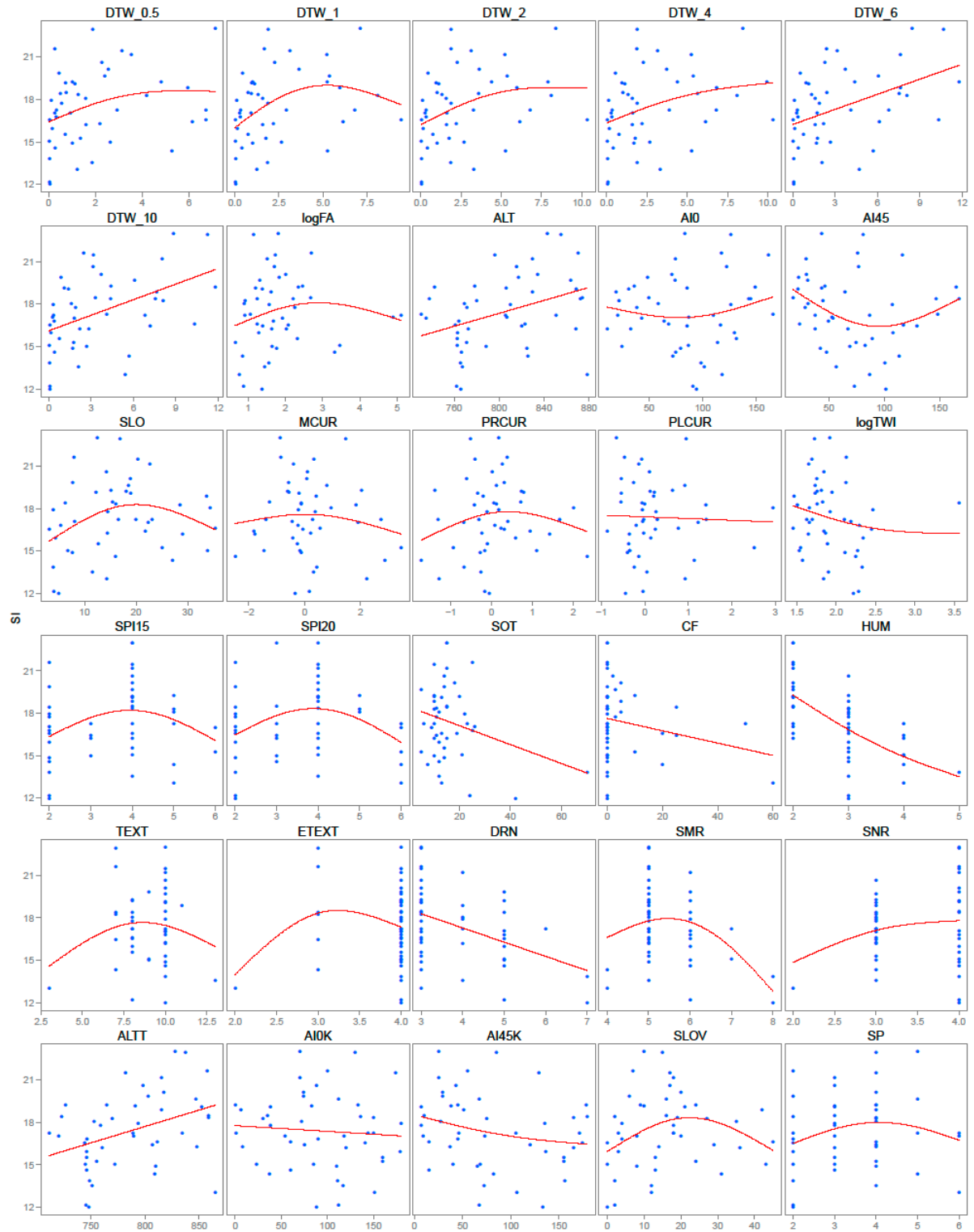


Figure S6. Scatter plots with penalized regression spline (three degrees of freedom) between environmental (remotely-sensed and ground-based measured) variables and SI for white spruce.

Part II. Mantel Correlograms

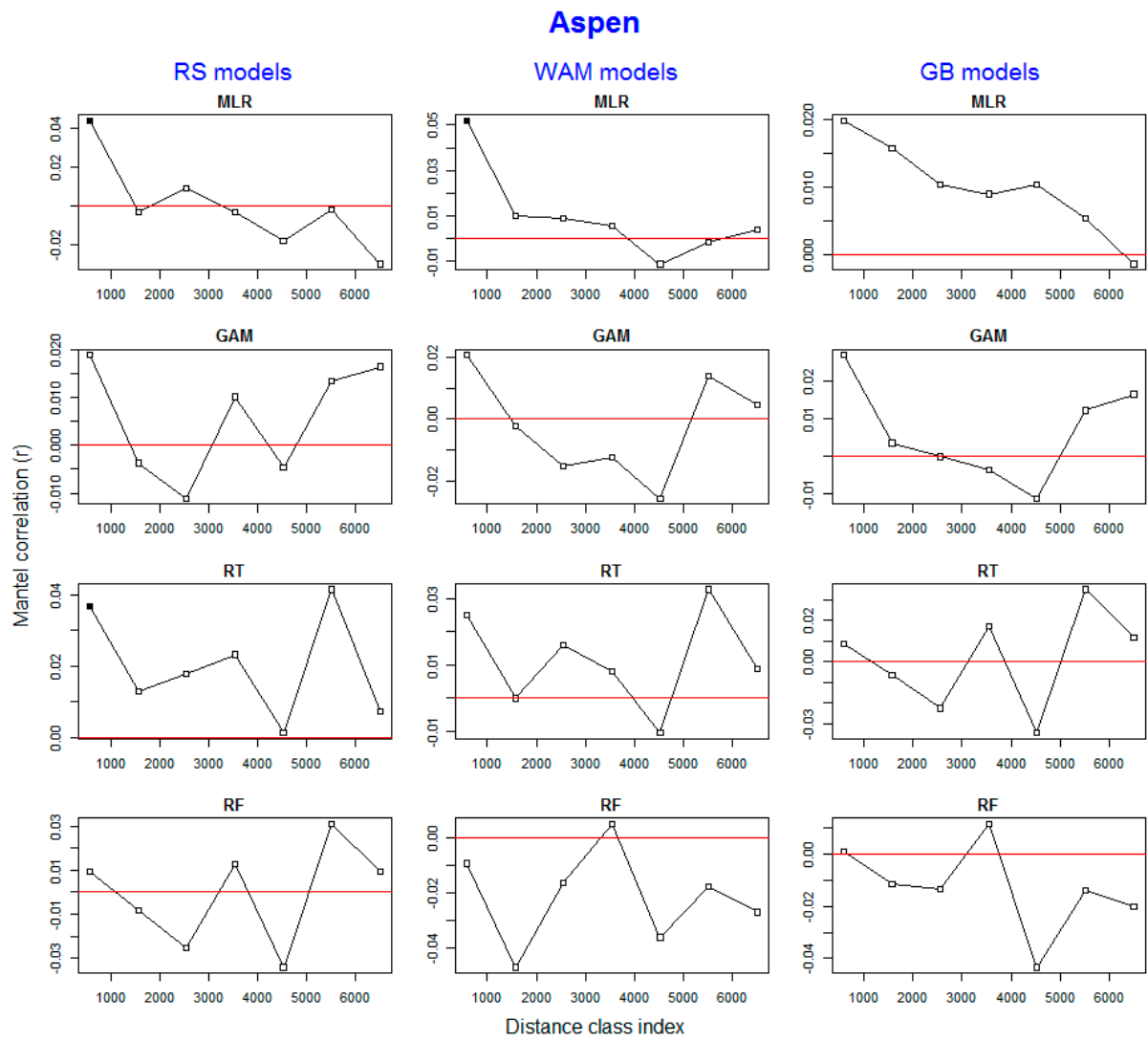


Figure S7. Spatial correlation structure for aspen presented using Mantel correlograms on model residuals based on Euclidian distance method. Black squares indicate significant ($p < 0.05$) spatial correlation at corresponding distance classes.

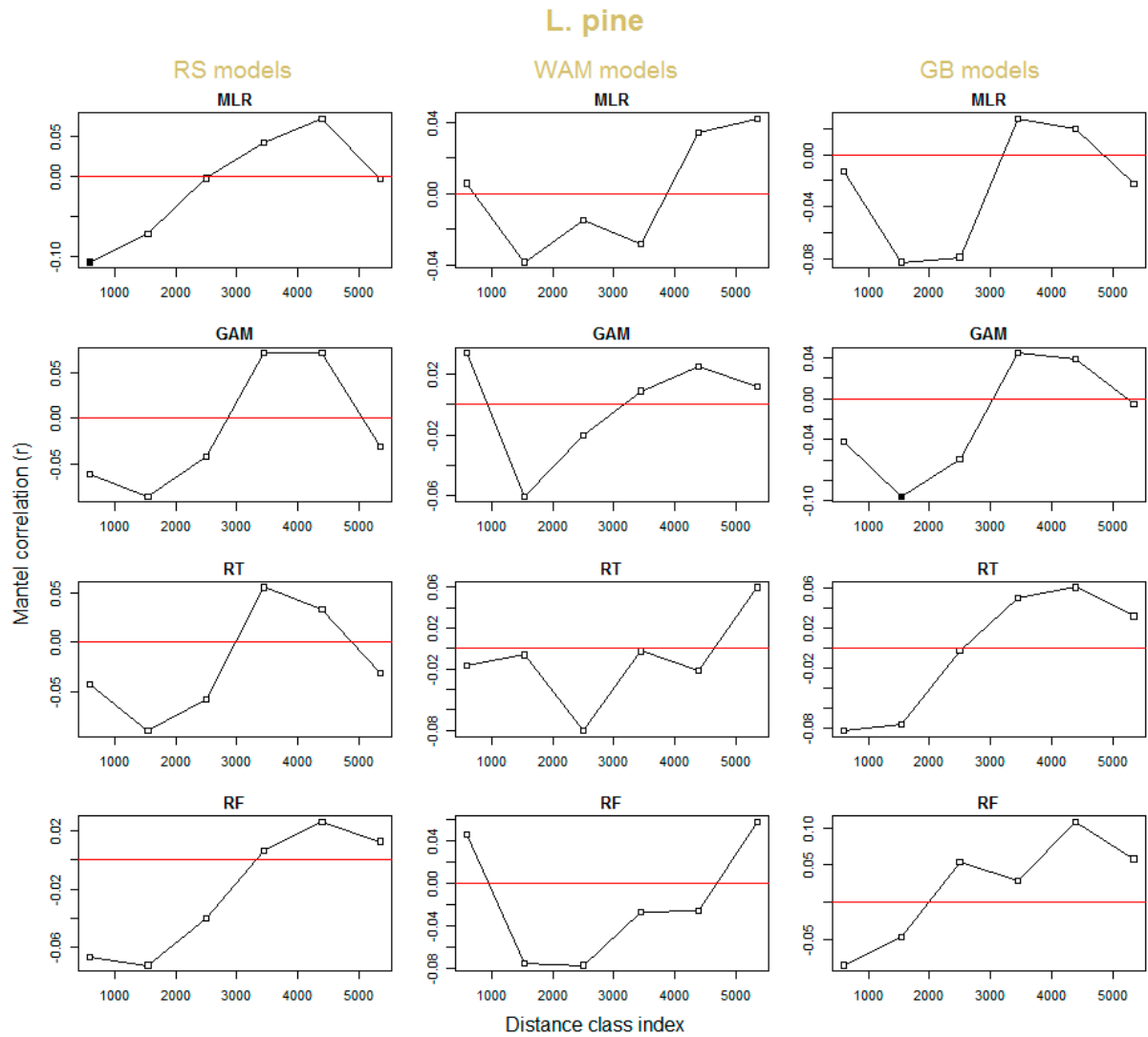


Figure S8. Spatial correlation structures for lodgepole pine presented using Mantel correlograms on model residuals based on Euclidian distance method. Black squares indicate significant ($p < 0.05$) spatial correlation at corresponding distance classes.

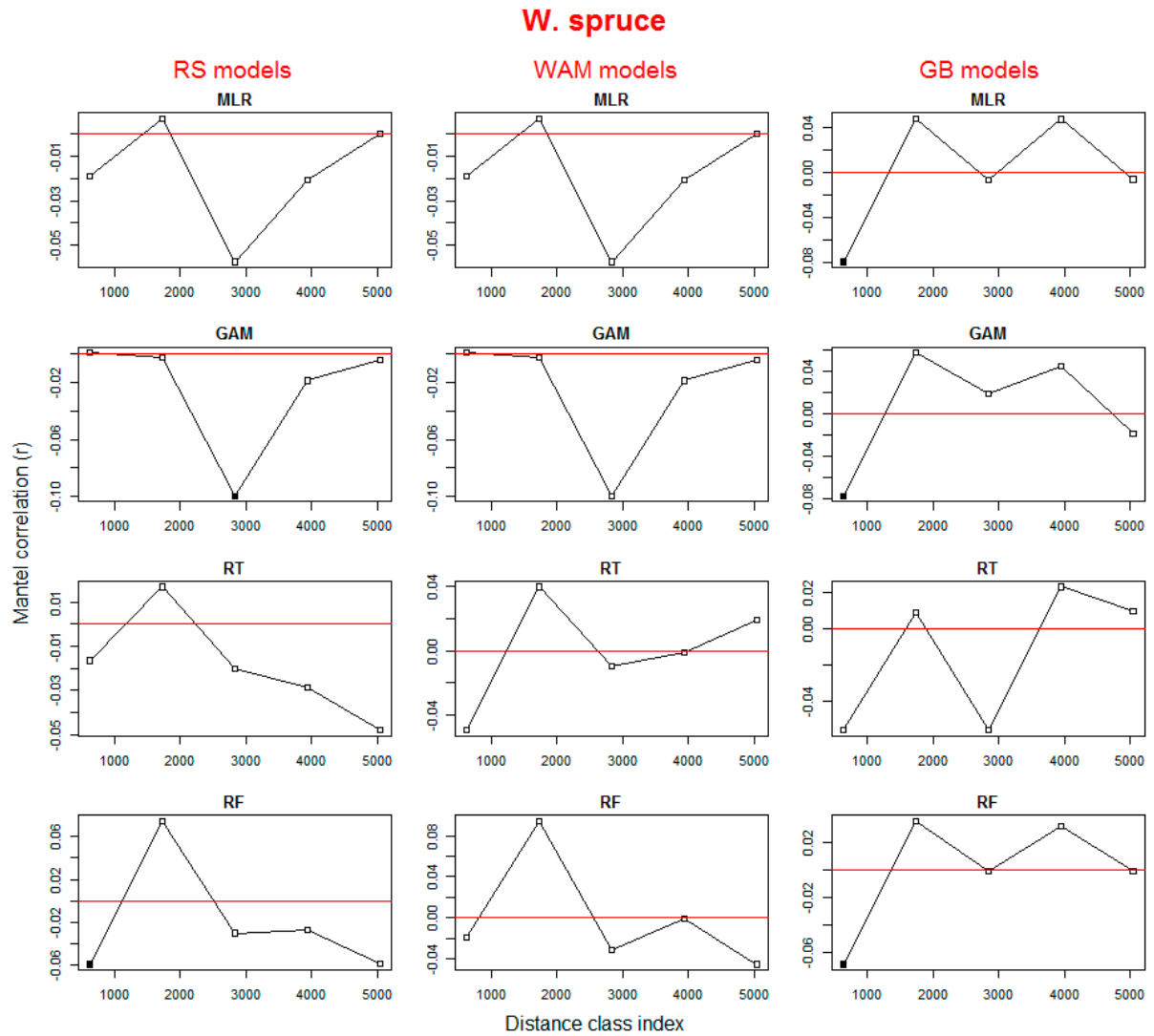


Figure S9. Spatial correlation structure for white spruce presented using Mantel correlograms on model residuals based on the Euclidian distance method. Black squares indicate significant ($p < 0.05$) spatial correlation at corresponding distance classes.

Part III. Correlation Analysis Results

Table S4. Kendall's rank correlation coefficient (τ) matrix between remotely-sensed environmental and soil attributes (N = 201). Bolded numbers indicate significance of relationship at $p < 0.05$.

[illegible]

Table S5. Kendall's rank correlation coefficient (τ) matrix between aspen SI and environmental variables (N = 97). Bolded numbers indicate significance of relationship at $p < 0.05$. Italicized numbers indicate the coefficient of determination from quadratic regression.

SI	-0.32	-0.30	-0.30	-0.27	-0.25	-0.22	0.34	-0.38	0.02	0.04	-0.33	-0.34	0.21	-0.36	0.33	-0.36	-0.43
DTW_0.5	0.85	0.74	0.68	0.64	0.62	-0.10	0.37	-0.09	0.06	0.60	0.27	-0.18	0.29	-0.57	0.39	0.43	
DTW_1	0.82	0.73	0.68	0.67	-0.09	0.37	-0.07	0.05	0.58	0.26	-0.15	0.28	-0.54	0.39	0.42		
DTW_2	0.82	0.76	0.72	-0.09	0.41	-0.07	0.04	0.54	0.27	-0.16	0.27	-0.50	0.38	0.45			
DTW_4	0.92	0.84	-0.08	0.38	0.06	0.04	0.54	0.26	-0.15	0.26	-0.48	0.34	0.40				
DTW_6	0.89	-0.06	0.40	-0.09	0.03	0.53	0.25	-0.14	0.25	-0.46	0.36	0.41					
DTW_10	-0.04	0.40	0.05	0.02	0.52	0.24	-0.14	0.24	-0.46	0.33	0.38						
FA	-0.14	0.02	0.00	-0.13	-0.46	0.36	-0.46	0.19	-0.35	-0.42							
ALT	0.08	0.00	0.37	0.25	-0.18	0.21	-0.30	0.35	0.35								
AI0	0.46	0.03	0.03	-0.06	-0.04	0.01	0.05	0.02									
AI45	0.02	-0.02	0.07	-0.04	0.00	-0.02	-0.02										
SLO	0.28	-0.17	0.30	-0.79	0.46	0.49											
MCUR	-0.73	0.68	-0.27	0.54	0.64												
PRCUR	-0.41	0.15	-0.42	-0.46													
PLCUR	-0.30	0.48	0.60														
TWI	-0.42	-0.46															
SPI15	0.84																
SPI20																	
SI	0.12	-0.18	-0.16	-0.03	0.02	0.27	0.42	0.31	-0.38	0.07	-0.19	-0.26	-0.33				
SOT	-0.19	-0.36	0.01	-0.01	0.30	0.28	0.29	0.07	0.06	0.00	0.07	-0.11					
CF	0.21	-0.06	0.03	-0.13	-0.31	-0.22	0.03	0.04	0.04	0.05	0.18						
HUM	-0.17	-0.06	-0.25	-0.26	-0.46	-0.09	0.04	0.06	-0.09	0.13							
TEXT	0.72	0.13	0.04	0.17	0.09	0.03	0.00	0.01	-0.06								
ETEXT	0.12	0.06	0.20	-0.03	-0.02	-0.03	0.01	-0.13									
DRN	0.70	0.31	-0.16	0.06	0.04	-0.25	-0.45										
SMR	0.38	-0.21	0.00	0.01	-0.31	-0.61											
SNR	-0.08	0.03	0.02	-0.04	-0.23												
ALTT	0.10	0.08	0.32	0.24													
AI0K	0.54	0.05	-0.03														
AI45K	0.09	-0.13															
SLOV	0.31																
SP																	

Table S6. Kendall's rank correlation coefficient (τ) matrix between lodgepole pine SI and environmental variables (N = 50). Bolded numbers indicate significance of relationship at $p < 0.05$ (* $p = 0.06$). Italicized numbers indicate coefficient of determination from quadratic regression.

SI	0.46	0.52	0.52	0.52	0.54	0.52	-0.24	-0.24	0.18*	<i>0.03</i>	0.41	0.27	-0.20	0.28	-0.38	0.33	0.34
DTW_0.5		0.92	0.89	0.79	0.74	0.72	-0.24	-0.01	0.08	0.02	0.72	0.31	-0.18	0.36	-0.69	0.49	0.52
DTW_1			0.94	0.82	0.79	0.76	-0.20	-0.01	0.06	-0.01	0.68	0.30	-0.16	0.34	-0.64	0.46	0.49
DTW_2				0.87	0.83	0.80	-0.18	-0.03	0.05	-0.03	0.66	0.29	-0.15	0.35	-0.62	0.45	0.48
DTW_4					0.93	0.89	-0.14	-0.08	0.09	-0.02	0.60	0.26	-0.18	0.28	-0.54	0.37	0.39
DTW_6						0.95	-0.13	-0.08	0.10	-0.02	0.59	0.28	-0.20	0.30	-0.54	0.37	0.39
DTW_10							-0.11	-0.08	0.13	0.02	0.57	0.26	-0.17	0.28	-0.52	0.35	0.37
FA								0.12	-0.12	-0.10	-0.20	-0.55	0.44	-0.50	0.31	-0.45	-0.48
ALT									-0.25	-0.24	0.05	-0.01	0.04	-0.02	-0.07	0.08	0.06
AI0										0.57	0.05	0.06	-0.05	0.07	-0.06	-0.01	0.01
AI45											0.01	-0.04	<i>0.04</i>	0.02	-0.05	0.02	0.03
SLO												0.29	-0.20	0.33	-0.80	0.57	0.58
MCUR													-0.66	0.65	-0.39	0.42	0.47
PRCUR														-0.31	0.26	-0.28	-0.32
PLCUR															-0.43	0.42	0.46
TWI																-0.56	-0.59
SPI15																	0.97
SPI20																	
SI	-0.03	<i>0.01</i>	-0.26	-0.08	-0.09	-0.18	-0.19	0.51	-0.20	0.19	<i>0.09</i>	0.34	0.22				
SOT		-0.12	0.05	0.12	0.09	0.26	0.40	<i>0.13</i>	0.14	-0.14	-0.09	0.02	-0.13				
CF			0.00	0.11	0.06	-0.36	-0.38	0.11	0.29	<i>0.01</i>	0.01	0.27	0.33				
HUM				0.22	0.22	0.22	0.21	-0.28	0.23	-0.06	-0.02	-0.02	-0.01				
TEXT					0.70	0.07	0.17	-0.01	0.15	-0.12	-0.12	-0.11	-0.07				
ETEXT						0.05	0.08	-0.03	0.14	0.04	-0.09	0.05	-0.01				
DRN							0.70	0.23	-0.18	0.05	0.21	-0.31	-0.54				
SMR								0.19	-0.01	0.08	0.10	-0.29	-0.70				
SNR									-0.06	0.18	0.18	0.42	0.06				
ALTT										-0.22	-0.20	0.15	0.05				
AI0K											0.55	0.08	0.07				
AI45K												0.08	-0.11				
SLOV													0.39				
SP																	

Table S7. Kendall's rank correlation coefficient (τ) matrix between white spruce SI and environmental variables (N = 45). Bolded numbers indicate the significance of the relationship at $p < 0.05$. Italicized numbers indicate the coefficient of determination from quadratic regression (*exponential transformation).

SI	0.23	0.26	0.26	0.25	0.31	0.34	<i>0.09*</i>	0.25	<i>0.01</i>	<i>0.09</i>	<i>0.10</i>	<i>0.05</i>	<i>0.05</i>	-0.01	-0.12	0.09	<i>0.12</i>
DTW_0.5		0.89	0.80	0.78	0.72	0.69	-0.24	0.26	-0.17	-0.13	0.59	0.16	-0.11	0.13	-0.62	0.45	0.44
DTW_1			0.87	0.84	0.77	0.72	-0.22	0.28	-0.17	-0.14	0.54	0.17	-0.10	0.13	-0.57	0.40	0.39
DTW_2				0.96	0.88	0.82	-0.16	0.25	-0.14	-0.10	0.47	0.20	-0.15	0.14	-0.52	0.42	0.41
DTW_4					0.90	0.83	-0.15	0.23	-0.13	-0.09	0.46	0.19	-0.14	0.14	-0.51	0.40	0.39
DTW_6						0.93	-0.14	0.28	-0.09	-0.10	0.44	0.18	-0.13	0.13	-0.50	0.39	0.38
DTW_10							-0.14	0.32	-0.07	-0.06	0.43	0.15	-0.10	0.13	-0.48	0.40	0.38
FA								-0.12	0.00	-0.03	-0.17	-0.40	0.25	-0.31	0.28	-0.33	-0.34
ALT									-0.21	-0.30	<i>0.06</i>	0.02	-0.06	-0.07	-0.19	<i>0.12</i>	0.15
AI0										0.56	-0.26	-0.05	0.03	-0.02	0.25	-0.16	-0.14
AI45											-0.17	-0.02	-0.01	0.01	0.17	-0.11	-0.07
SLO												<i>0.09</i>	<i>0.08</i>	0.22	-0.82	<i>0.51</i>	0.51
MCUR													-0.65	0.55	-0.25	0.48	0.48
PRCUR														0.23	0.17	-0.37	-0.37
PLCUR															-0.23	0.40	0.44
TWI																-0.59	-0.59
SPI15																	0.95
SPI20																	
SI	-0.03	-0.01	-0.54	<i>0.04</i>	<i>0.05</i>	-0.28	<i>0.18</i>	0.12	0.26	-0.08	-0.16	<i>0.10</i>	<i>0.05</i>				
SOT		-0.19	-0.21	0.07	0.09	0.32	0.45	0.49	0.02	0.14	-0.03	-0.51	-0.55				
CF			0.06	-0.26	-0.18	-0.19	-0.29	-0.45	0.11	-0.05	0.00	0.22	0.22				
HUM				-0.11	-0.18	0.13	<i>0.18</i>	-0.34	-0.22	-0.03	0.21	0.07	0.06				
TEXT					0.63	0.08	0.12	0.11	0.03	-0.13	-0.22	-0.02	0.01				
ETEXT						0.35	<i>0.33</i>	<i>0.38</i>	-0.35	-0.04	-0.18	-0.15	-0.25				
DRN							0.84	0.34	-0.46	0.19	0.25	-0.36	-0.58				
SMR								0.49	-0.39	0.17	0.15	-0.48	-0.68				
SNR									-0.20	0.17	0.02	-0.46	-0.49				
ALTT										-0.19	-0.25	0.19	0.28				
AI0K											0.56	-0.25	-0.17				
AI45K												-0.15	-0.07				
SLOV													<i>0.40</i>				
SP																	

Part IV. Variable Selection Using Random Forest (VSURF)

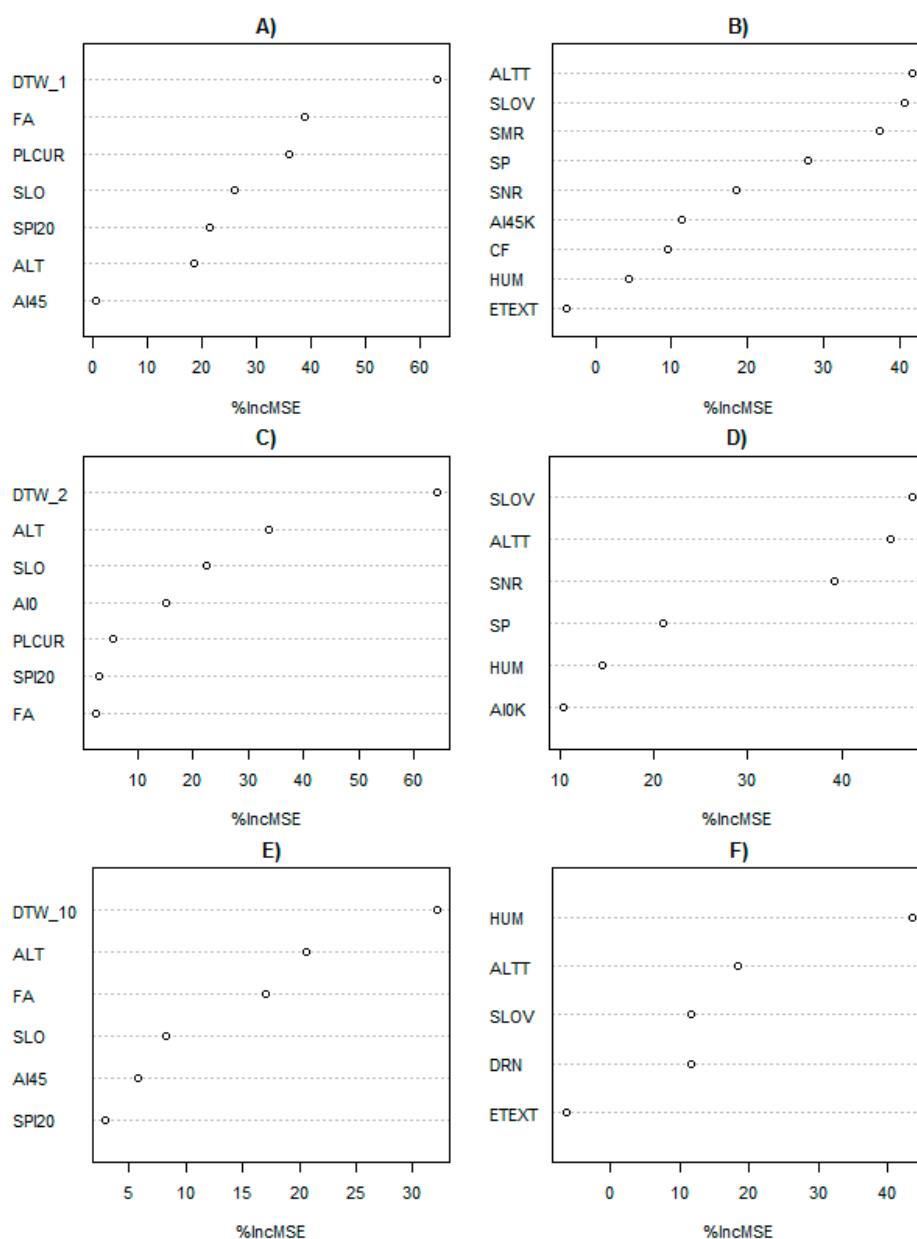


Figure S10. Variable importance plots for aspen (A, B), pine (C, D), and spruce (E, F). SI random forest models built with all potential remotely-sensed (A, C, E) and ground-based measured (B, D, F) variables. %IncMSE: variable importance measure indicating the average percent change in the mean square error when the particular variable is removed while all others are retained unchanged. Important variables should cause relatively large %IncMSE.

Part V. Responses in SI on Site Factors

Table S8. Summary by species of responses in SI on site factors included in the final models; **↑**: positive, **↓**: negative, **→**: no response, (**↑**): trend detected only by some statistical methods, * no significant relationship between SI and single particular predictor.

Selected site factors	Aspen SI	L. pine SI	W. spruce SI
↑ DTW (wet→dry)	(↑) ↓	↑	↑
↑ FA (dry→wet)	↑ →	↓ →	↑ →
↑ Altitude	↓	↓	↑
↑ Aspect (cold→warm)	↓	↑ *	→*
↑ Slope	↓	↑	↑ ↓
↑ Slope position (depression→crest)	(↑) ↓	↑	↑ ↓
↑ Curvature (convex→concave)	↓	↑	↑ ↓ *
↑ SMR (dry→wet)	↑ (↓)	↓ *	↑ ↓
↑ Drainage (well→poor)	↑	↓ *	↑ ↓
↑ SNR (poor→rich)	↑	↑	↑ *
↑ Humus form (mor→mull)	↑	↑	↑

Part VI. Regression Tree Models

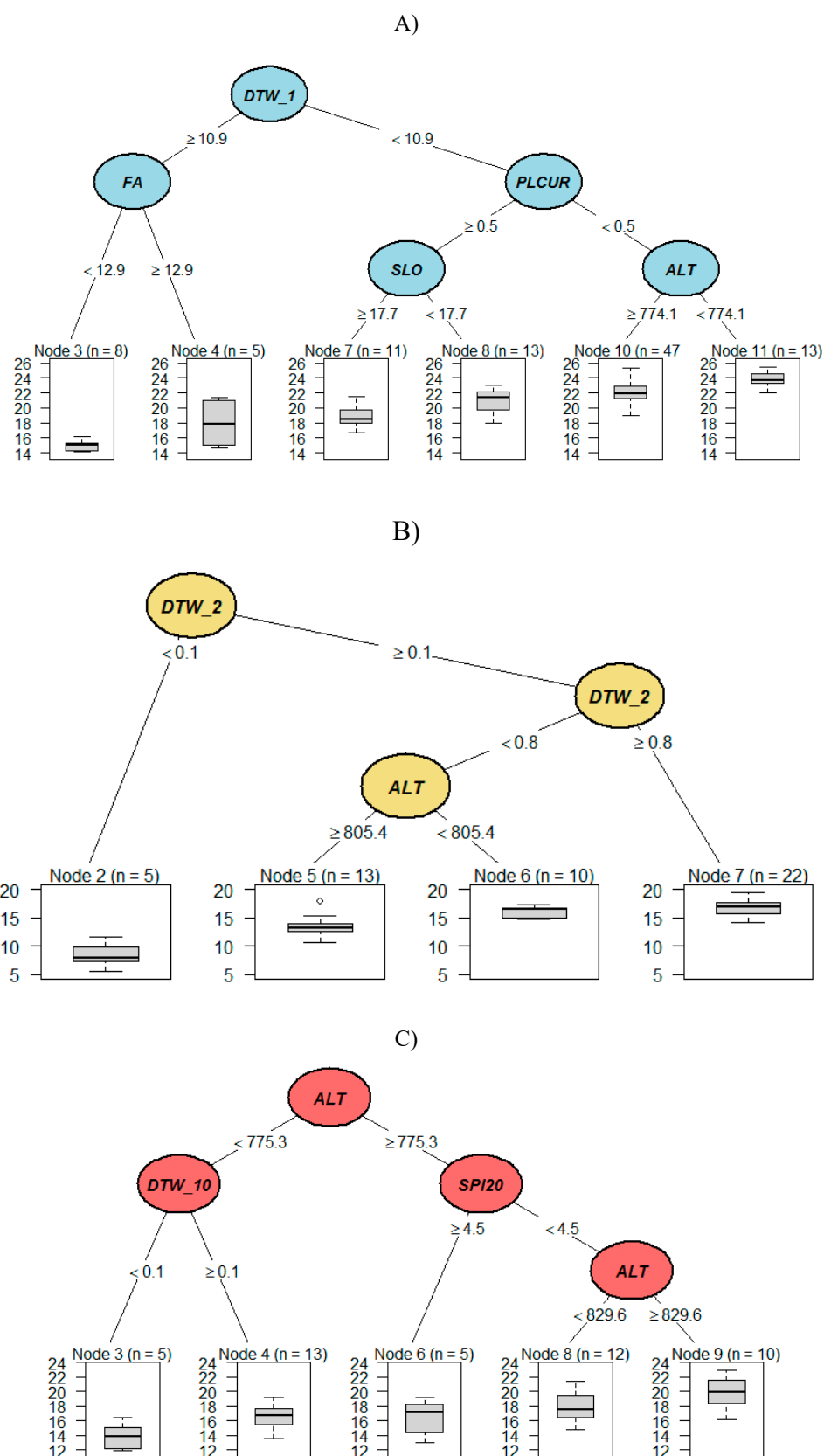
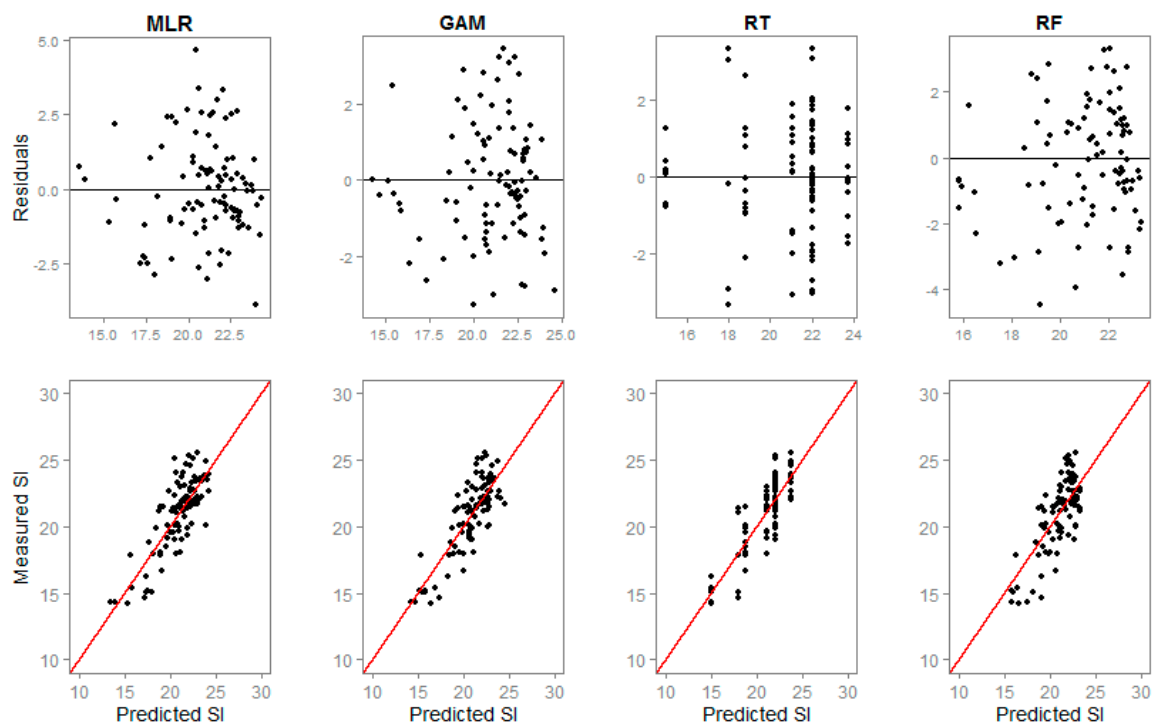


Figure S11. Regression tree SI models based on remotely-sensed data; (A) aspen, (B) lodgepole pine, and (C) white spruce.

Aspen - RS models



Aspen - GB models

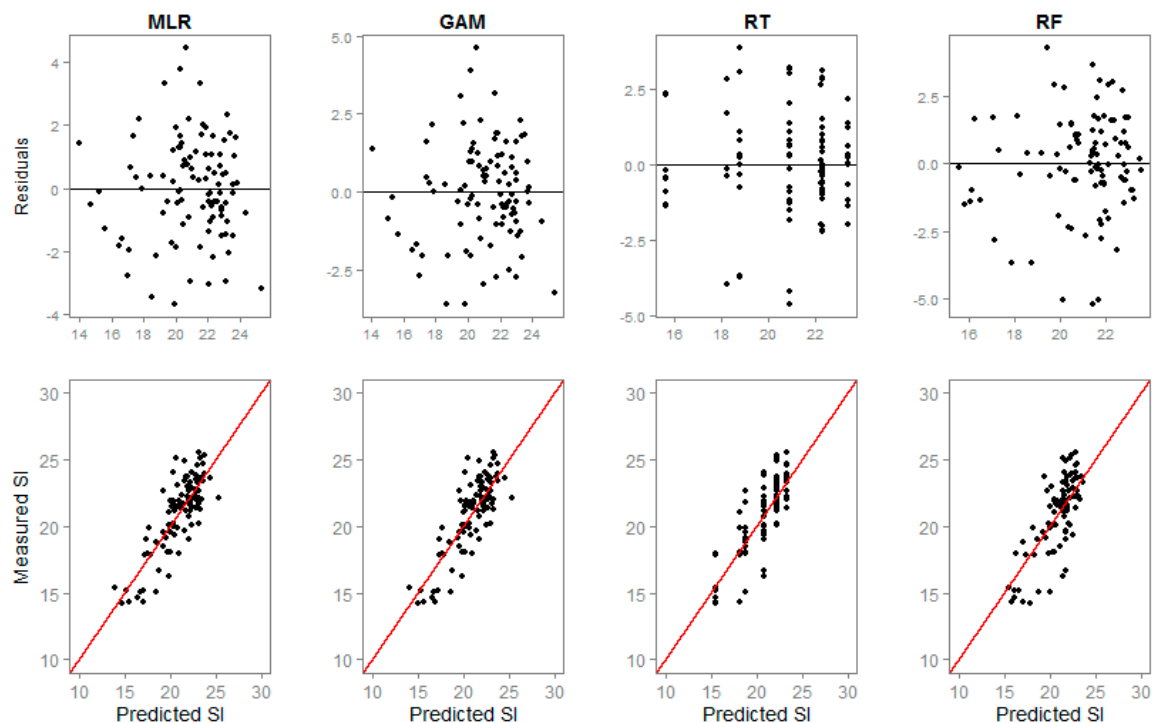
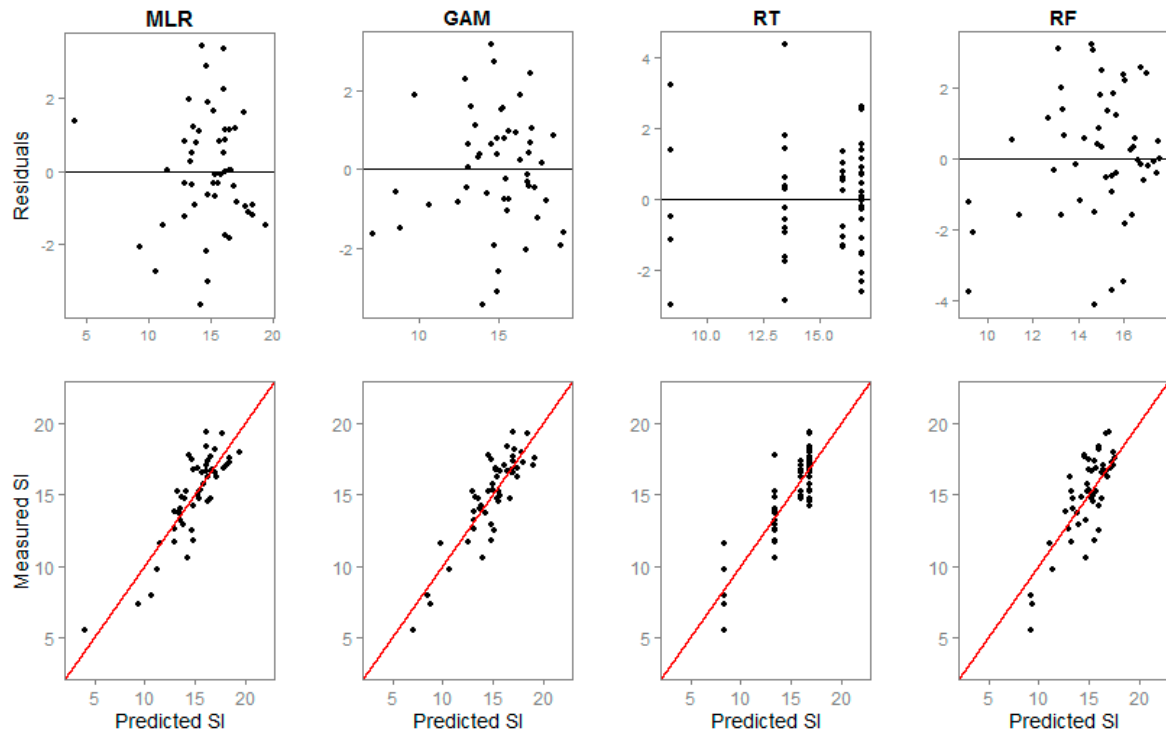


Figure S12. Residual and measured vs. predicted plots for aspen by data sources and modeling techniques. The 1:1 line is shown in red.

L. pine - RS models



L. pine - GB models

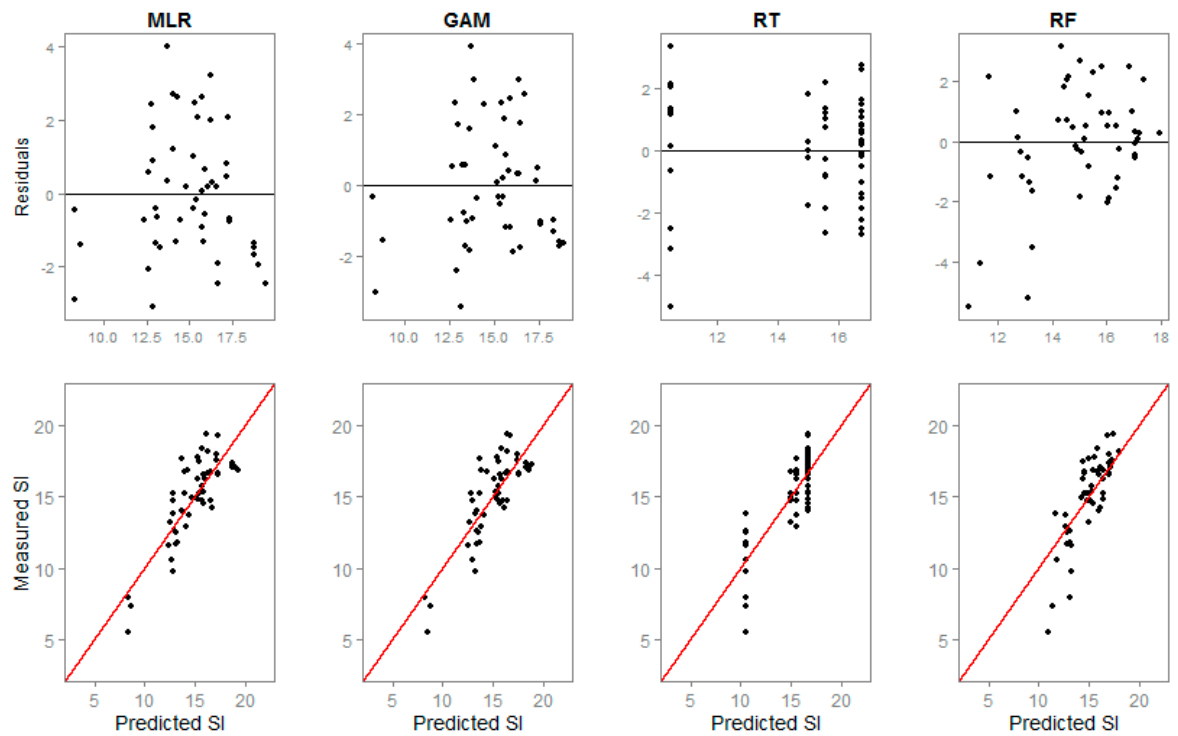


Figure S13. Residual and measured vs. predicted plots for pine by data sources and modeling techniques. The 1:1 line is shown in red.

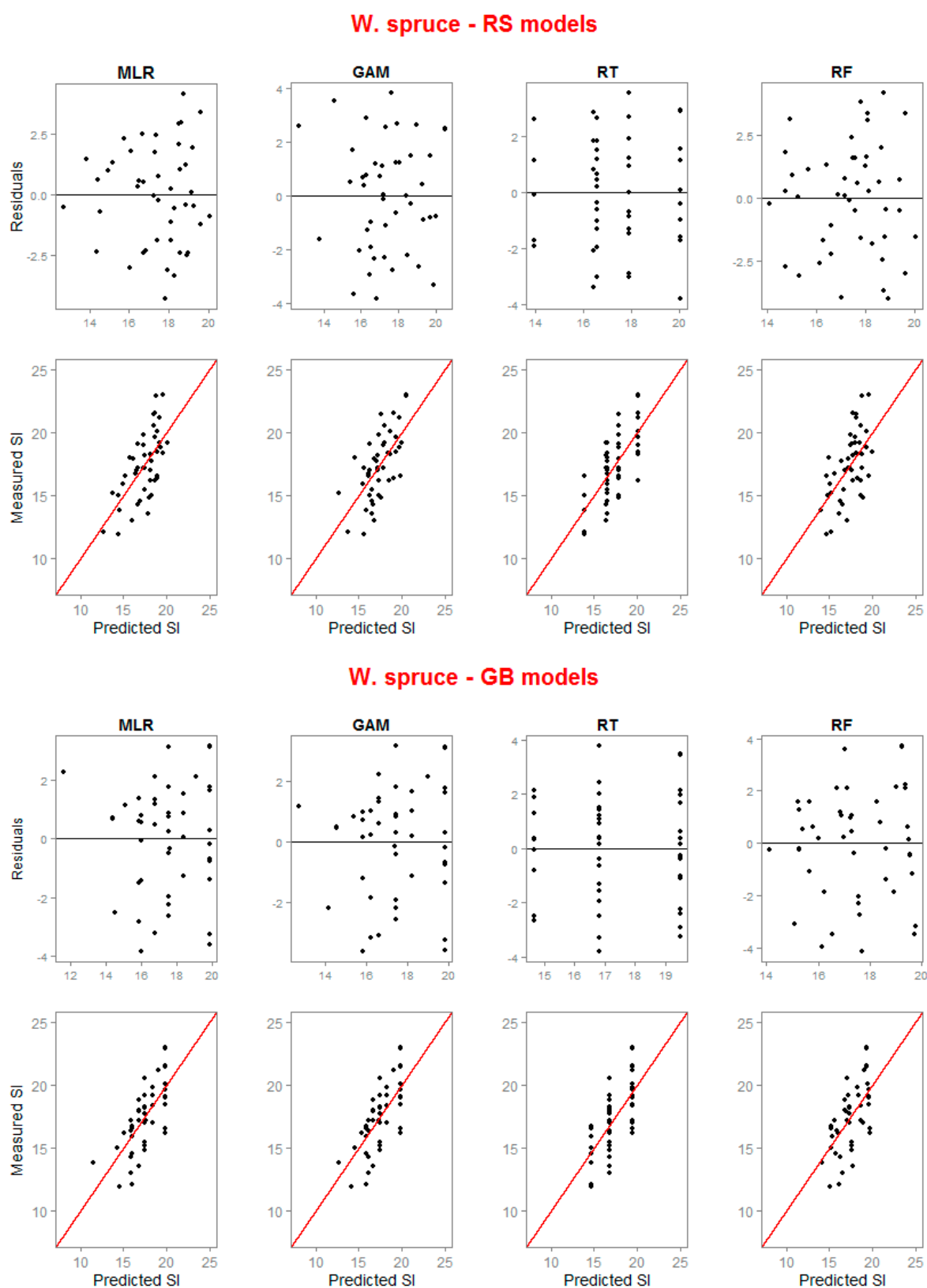


Figure S14. Residual and measured vs. predicted plots for spruce by data sources and modeling techniques. The 1:1 line is shown in red.