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Predicting the Integrated Fire Resistance of Wildland–Urban Interface Plant Communities by Spatial Structure Analysis Learning for Shanghai, China

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Abstract: Fire is a prevalent hazard that poses a significant risk to public safety and societal progress. The continuous expansion of densely populated urban areas, exacerbated by global warming and the increasing intensification of urban heat islands, has led to a notable increase in the frequency and severity of fires worldwide. Incorporating measures to withstand different types of calamities has always been a crucial aspect of urban infrastructure. Well-designed plant communities play a pivotal role as a component of green space systems in addressing climate-related challenges, effectively mitigating the occurrence and spread of fires. This study conducted field research on 21 sites in the green belt around Shanghai, China, quantifying tree morphological indexes and coordinate positions. The spatial structure attributes of different plant communities were analyzed by principal component analysis, CRITIC weighting approach, and stepwise regression analysis to build a comprehensive fire resistance prediction model. Through this research, the relationship between community spatial structures and fire resistance was explored. A systematic construction of a prediction model based on community spatial structures for fire resistance was undertaken, and the fire resistance performance could be quickly judged by easily measured tree morphological indexes, providing valuable insights for the dynamic prediction of fire resistance. According to the evaluation and ranking conducted by the prediction model, the *Celtis sinensis*, *Sapindus saponaria*, *Osmanthus fragrans*, *Koelreuteria paniculata*, and *Distylium racemosum* + *Populus euramericana* 'I-214' communities exhibited a high level of fire resistance. On the other hand, the *Koelreuteria bipinnata* + *Ligustrum lucidum*, *Ginkgo biloba* + *Camphora officinarum* + *Ligustrum lucidum*, and *Ligustrum lucidum* + *Sapindus saponaria* communities obtained lower scores and were positioned lower in the ranking. It is emphasized that the integration of monitoring and regulation is essential to ensure the ecological integrity and well-being of green areas in the Wildland–Urban Interface.

Keywords: urban greening; plant community; fire resistance; spatial structure; prediction model; surface litter

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Table S1. KMO and Bartlett's Test.

KMO sampling suitability quantity		**0.633**
Bartlett's Test of Sphericity	Approximate Chi-squared value	168.635
	Degree of freedom	28
	Significance	0.000

Table S2. Total variance interpretation table of community spatial structure factors.

Component	**Initial eigenvalue**			**Extract the load sum of squares**			**Square sum of rotational loads**		
	Total	Variance proportion	Accumulation %	Total	Variance proportion	Accumulation %	Total	Variance proportion	Accumulation %
1	4.136	51.706	51.706	4.136	51.706	51.706	2.980	37.246	37.246
2	1.950	24.369	76.075	1.950	24.369	76.075	2.424	30.303	67.549
3	1.237	15.463	91.538	1.237	15.463	91.538	1.919	23.989	91.538
4	0.287	3.590	95.128						
5	0.240	3.000	98.127						
6	0.092	1.148	99.276						
7	0.045	0.565	99.840						
8	0.013	0.160	100.000						

Table S3. Quality fire resistance prediction model explanatory degree.

Model	**R**	**R-squared**	**Adjusted R-square**	**Errors in standard estimate**
1	0.609[a]	0.371	0.329	0.04879

a. Predictive variables: (constant), stem form factor F_1
b. Dependent variable: mass fire resistance Y_1

Table S4. Quality fire resistance prediction model variance explanation.

Model		**Quadratic sum**	**Degree of freedom**	**Mean square**	**F**	**Significance**
1	Regression	0.021	1	0.021	8.855	0.009
	Residual error	0.036	15	0.002		
	Total	0.057	16			

Table S5. Quality fire resistance prediction model coefficient.

Model				**Standardized coefficient**	**t**	**Significance**	**Colinearity statistic**	
				Beta			Tolerance	VIF
1	(Constant)	0.206	0.029		7.221	0.000		
	F_1	-0.065	0.022	-0.609	-2.976	0.009	1.000	1.000

Table S6. Spatial distribution fire resistance prediction model explanatory degree.

Model	Variable	R	R-squared	Adjusted R-square	Errors in standard estimate
1	F_3、F_1、F_2	0.589	0.347	0.196	0.06431
2	F_3	0.352	0.124	0.066	0.06933
3	F_2、F_1	0.419	0.176	0.058	0.06960
4	F_3、F_2	0.407	0.166	0.047	0.07002
5	F_1、F_3	0.352	0.124	-0.001	0.07175
6	F_2	0.105	0.011	-0.055	0.07366
7	F_1	0.089	0.008	-0.058	0.07377

Table S7. Spatial distribution fire resistance prediction model variance explanation.

Model	Variable		Quadratic sum	Degree of freedom	Mean square	F	Significance
1	F_3、F_1、F_2	Regression	0.029	3	0.010	2.300	0.125
		Residual error	0.054	13	0.004		
		Total	0.082	16			
2	F_3	Regression	0.010	1	0.010	2.122	0.166
		Residual error	0.072	15	0.005		
		Total	0.082	16			
3	F_2、F_1	Regression	0.014	2	0.007	1.493	0.258
		Residual error	0.068	14	0.005		
		Total	0.082	16			
4	F_3、F_2	Regression	0.014	2	0.007	1.392	0.281
		Residual error	0.069	14	0.005		
		Total	0.082	16			
5	F_1、F_3	Regression	0.010	2	0.005	0.992	0.395
		Residual error	0.072	14	0.005		
		Total	0.082	16			
6	F_2	Regression	0.001	1	0.001	0.167	0.689
		Residual error	0.081	15	0.005		
		Total	0.082	16			
7	F_1	Regression	0.001	1	0.001	0.121	0.733
		Residual error	0.082	15	0.005		
		Total	0.082	16			

Table S8. Spatial distribution fire resistance prediction model coefficient.

Model				Standardized coefficient	t	Significance	Colinearity statistic	
				Beta			Tolerance	VIF
1	(Constant)	0.130	0.060		2.168	0.049		
	F_1	0.122	0.064	0.945	1.897	0.080	0.203	4.938
	F_2	-0.129	0.061	-1.061	-2.104	0.055	0.198	5.062
	F_3	0.068	0.037	0.429	1.844	0.088	0.929	1.077

Table S9. Combustion fire resistance prediction model explanatory degree.

Model	R	R-squared	Adjusted R-square	Errors in standard estimate
1	0.627[a]	0.394	0.353	0.06064
2	0.774[b]	0.599	0.542	0.05102

a. Predictors: (constant), F_2
b. Predictive variables: (constant), F_2, F_3
c. Dependent variable: Y_3

Table S10. Combustion fire resistance prediction model variance explanation.

Model		Quadratic sum	Degree of freedom	Mean square	F	Significance
1	Regression	0.036	1	0.036	9.735	0.007
	Residual error	0.055	15	0.004		
	Total	0.091	16			
2	Regression	0.055	2	0.027	10.469	0.002[c]
	Residual error	0.036	14	0.003		
	Total	0.091	16			

Table S11. Combustion fire resistance prediction model coefficient.

Model				Standardized coefficient	t	Significance	Collinearity statistic	
				Beta			Tolerance	VIF
2	(Constant)	0.131	0.046		2.818	0.014		
	F_2	0.096	0.022	0.751	4.283	0.001	0.931	1.074
	F_3	-0.078	0.029	-0.470	-2.681	0.018	0.931	1.074

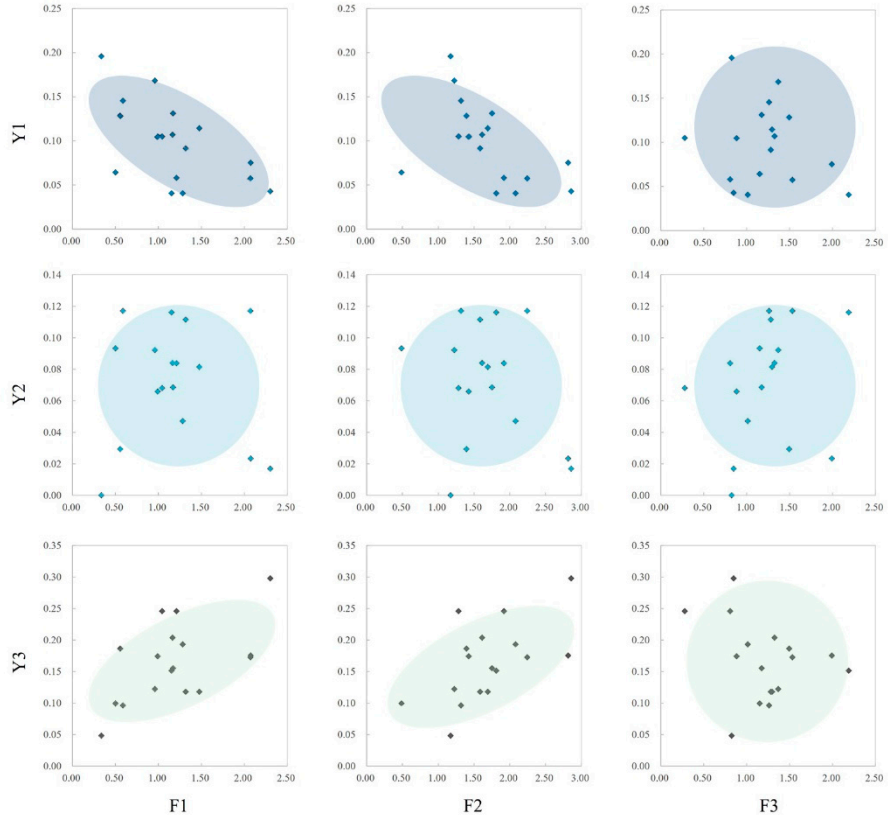
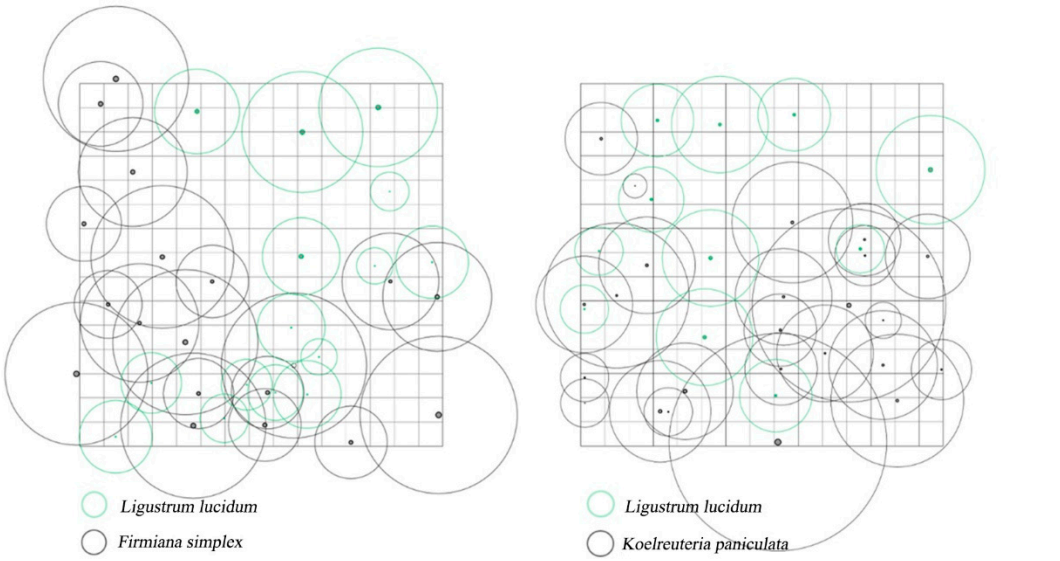


Figure S1. Scatter plot of community spatial structure factors and fire resistance evaluation. Where F1 is the stem shape factor, F2 is the crown cover factor, F3 is the density factor, Y1 is the mass characteristic fire resistance, Y2 is the spatial distribution fire resistance, and Y3 combustion fire resistance.



a) *Firmiana simplex*+ *Ligustrum lucidum* community. b) *Koelreuteria bipinnata*+ *Ligustrum lucidum* community.

Figure S2. Plan of a community with aggregated groups of trees.