Dispersal limitation dominates the spatial distribution of forest fuel loads in Chongqing, China

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Introduction

Background

- The amount of forest fuel load affects forest fire behavior indexes, such as the potential spread speed, fire intensity, and flame height during a forest fire.
- The stand model method establishes the mathematical relationship between the forest fuel load and the stand factor on a fine sample scale, and the forest fuel load can be predicted quickly by using forest survey data with high accuracy. This stand model method implicitly assumes that there are significant differences in the forest fuel loads among different stands; however, this hypothesis was not verified before modeling was conducted in various cases.
- Studies on the forest fuel load that have focused on the establishment of stand prediction models have only considered the influence of environmental and topographic factors and have not yet quantified the relative importance of environmental filtering and dispersal limitation on driving the formation of the forest fuel load spatial distribution.

Objective

This study aimed to explore the correlation between the forest fuel load and three explanatory variables (stand environment, topographic factors, and geospatial distance) to determine the key factors which influence the distribution of the forest fuel load .

Hypothesis

We hypothesized that: (1) there are significant differences in the composition of the forest fuel load in different stands, and (2) the spatial heterogeneity of the forest fuel load is mainly determined by environmental filtering and dispersal limitation, with the dominant effect being dispersal limitation.

Materials and Methods

- Analysis of similarities (ANOSIM)
- Nonmetric Multidimensional Scaling (NMDS)
- Mantel test
- Transformation-based redundancy analysis
- Variance partitioning

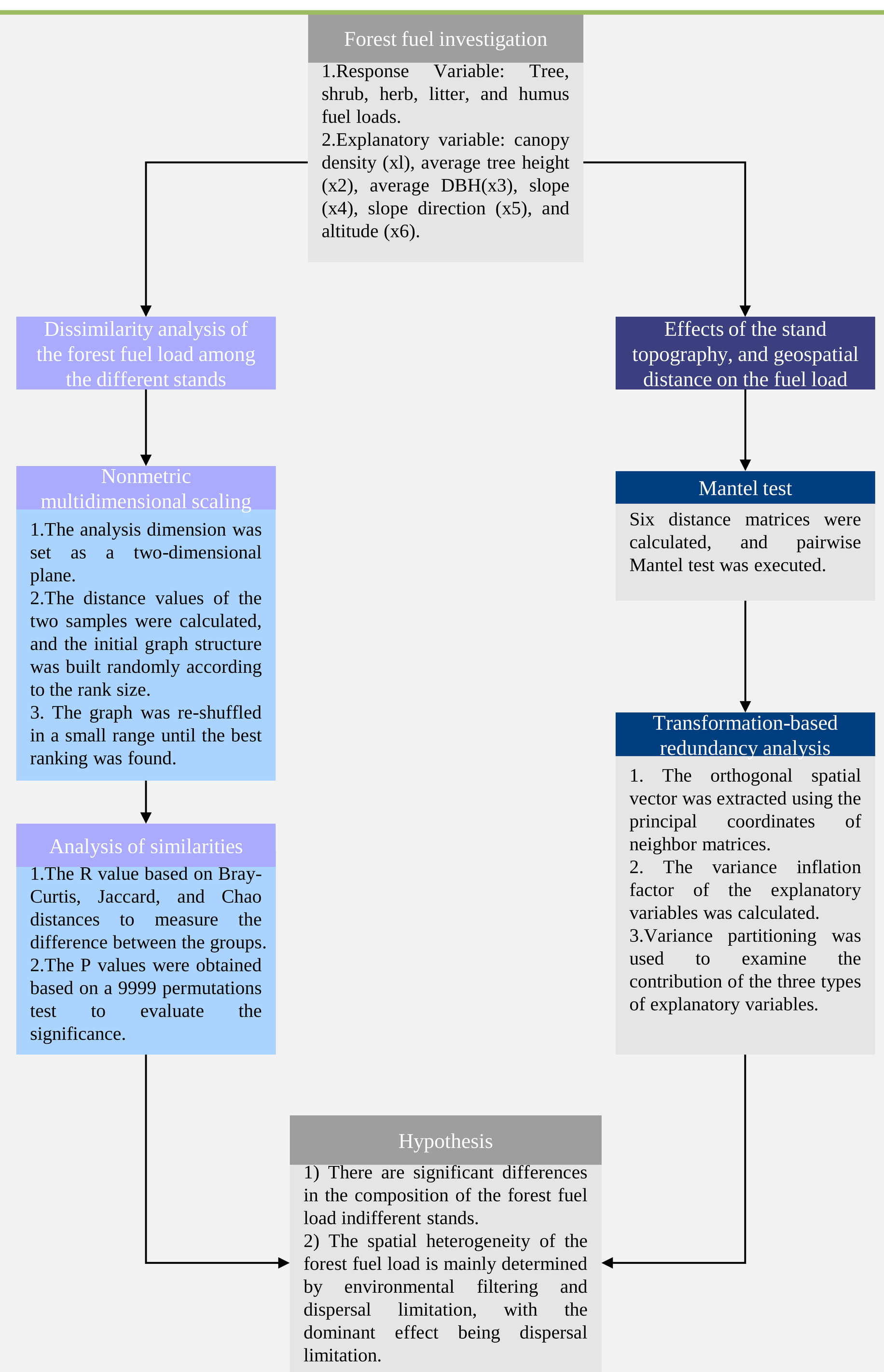

Figure 3. Flowchart of data collection and analysis.

Study site and experimental design

The study area was in Chongqing, China (28°10'–32°13' N, 105°17'–110°11' E)(Figure 1).

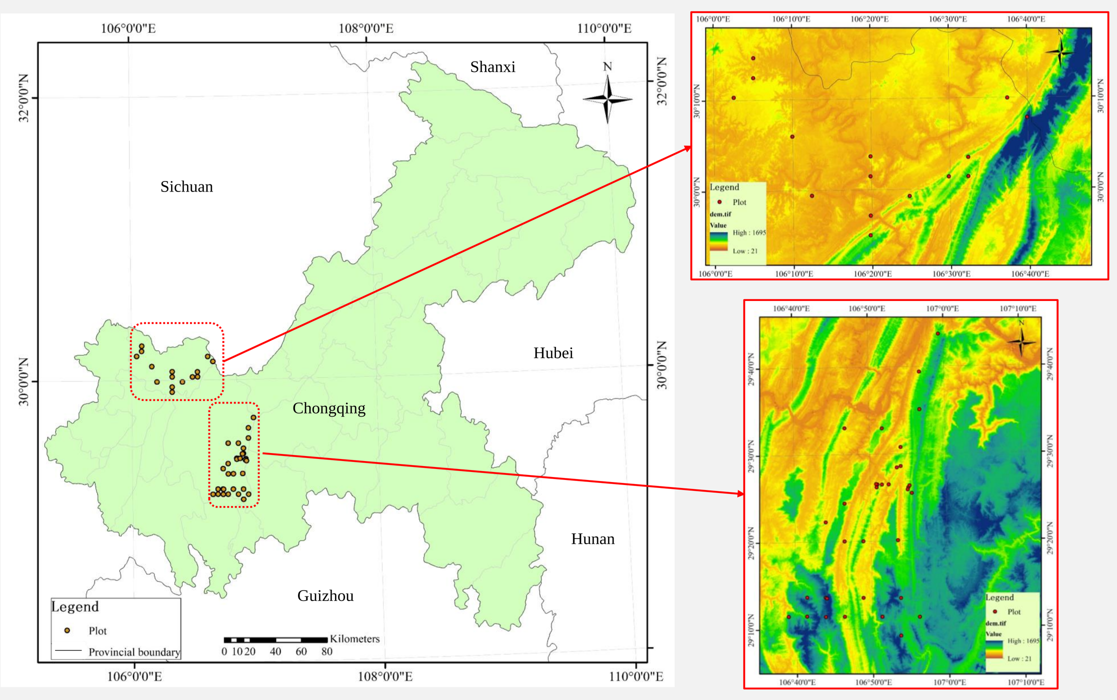

Figure 1. Map of sampled plots.

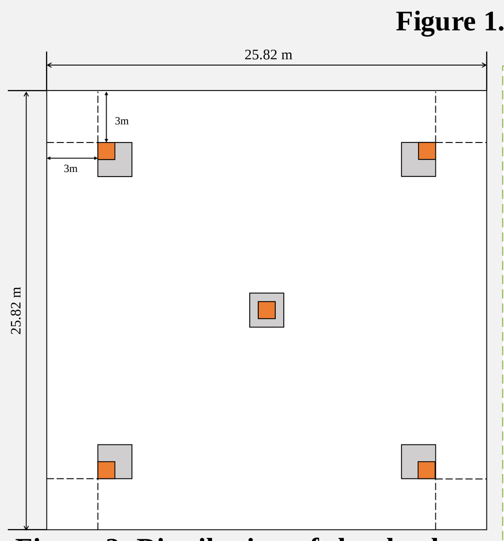

Figure 2. Distribution of the shrubs, herbs, litter, and humus quadrats in the plot.

A total of five quadrants were laid out in each plot (Figure 2). To determine the dry-wet ratio, the samples were put into the oven and continuously baked at 105 °C for 24 h to reach the absolute dry weight. Then, the dry weight of the different kinds of fuel in each sample square was weighed using an electronic balance to calculate the dry-wet ratio of the fuel (dry-wet ratio of the fuel = dry weight/wet weight).

Results

The interpreted variance of the first ranking axis was 15.14% (P < 0.05), and the interpreted variance of the second ranking axis was 12.74% (P < 0.05). The score of the explanatory variable was expressed as a vector in the tb-RDA ranking chart, and the length of the vector represents the magnitude of the correlation between the fuel load and the environment variable. Among the stand factors, the canopy density had a higher explanatory quantity and an average canopy height. Among the topographic factors, the altitude had a higher explanatory quantity(Figure 6).

The independent contribution of the geospatial distance (c = 14.66%) was greater than that of the stand factor (a = 9.51%) and significantly greater than the topographic factor (b = 0.35%). Additionally, the combination of the geospatial distance and topographic factors explained 4.66% of the variance.

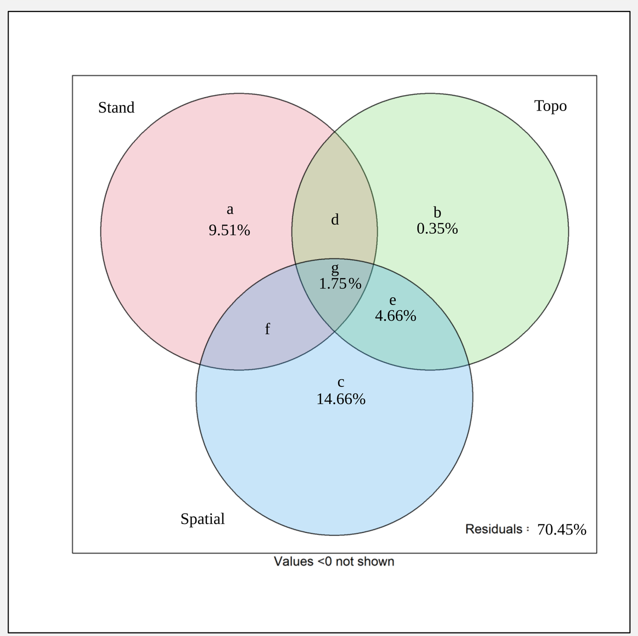

Figure 7. Variation partitioning of the fuel load by the stand environment (Stand), topographic factors (Topo), and geospatial factors (Spatial).

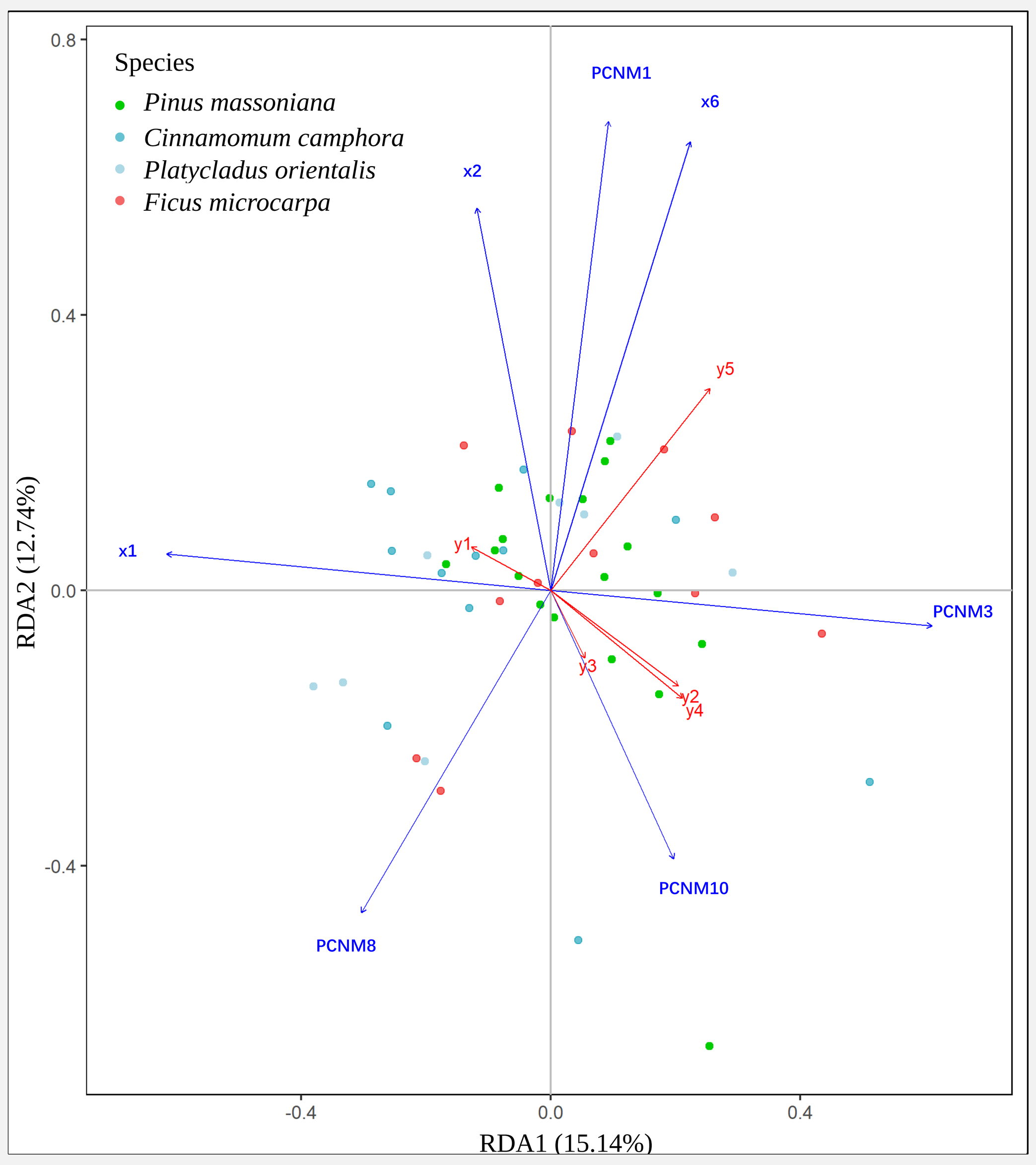

Figure 6. The transformation-based redundancy analysis results.

Based on the Mantel test results of the Bray-Curtis distance, the forest fuel load showed a significant positive correlation with the geospatial distance (R = 0.1524, P = 0.0171) and stand factors (R = 0.1349, P = 0.0277), while there was no significant correlation with the topographic factors (R = -0.0299, P = 0.6678) (Table 2).

The results showed that the entire model passed the permutation test ($F_{1,43}$ = 3.8759, P = 0.001), and the first and second ranking axes among the five ranking axes passed the permutation test ($F_{1,43}$ = 14.5806, P = 0.001; $F_{1,43}$ = 12.2652, P = 0.001). The canopy density, average canopy height, altitude, PCNM1, PCNM3, PCNM8, and PCNM10 had significant influences on the forest fuel loads (Table 3).

Table 2 Mantel test for a pairwise correlation between the distance matrix of the fuel load difference and the stand environmental factors, topographic factors, and geospatial distance.

Distance	Factor	R	P value
Bray-Curtis	Spatial	0.1524	0.0171
	Stand	0.1349	0.0277
	Topographic	-0.0299	0.6678
Jaccard	Spatial	0.1524	0.0189
	Stand	0.1349	0.0291
	Topographic	-0.0299	0.6680
Chao	Spatial	0.5419	1×10^{-4}
	Stand	0.1205	0.0232
	Topographic	0.0349	0.2863

Table 3. Permutation test (number of permutations: 999) and variance inflation factor (VIF) results for the explanatory variables.

Factor	Variable	F	P value	Significance	VIF
Stand	X1	5.5471	0.003	**	1.2396
	X2	3.7450	0.010	**	1.1757
Topographic	X6	4.4775	0.007	**	1.5254
Spatial	PCNM1	2.5071	0.050	*	1.4718
	PCNM3	3.3227	0.020	*	1.1934
	PCNM8	4.8914	0.008	**	1.1874
	PCNM10	2.6407	0.050	*	1.0446

Results

The confidence ellipse was obtained with a confidence level of 95%, which showed that the confidence ellipses of the different stands overlapped, demonstrating similarity between the groups.

The ANOSIM based on the Bray-Curtis distance suggested that there were significant differences in the forest fuel loads between the different stands.

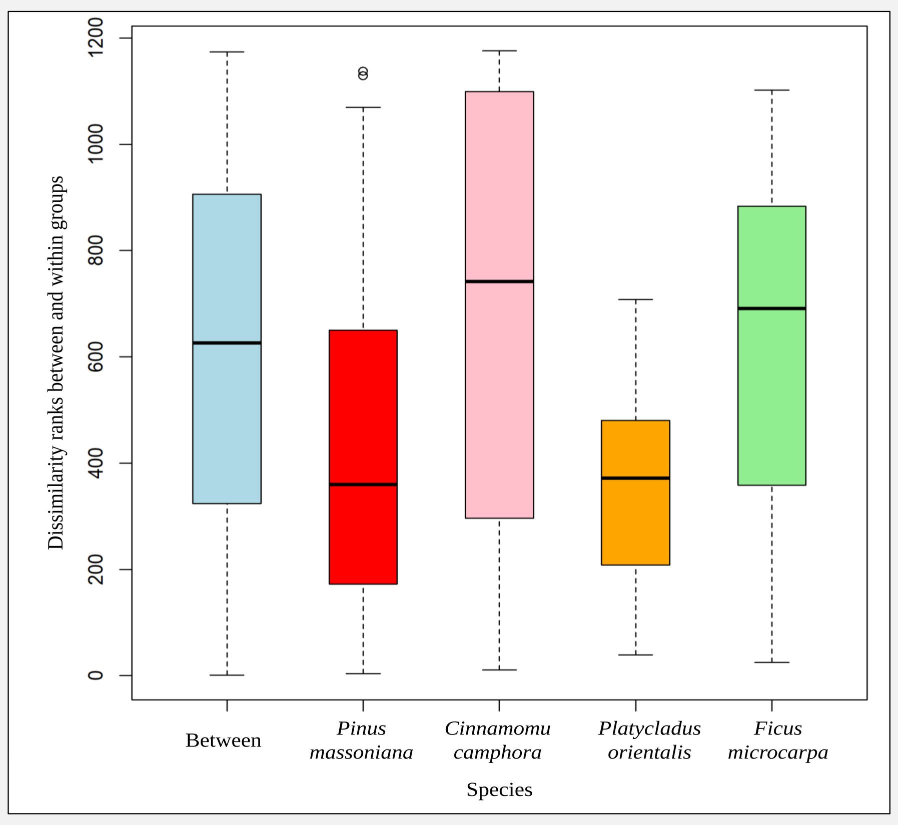

Figure 4. Analysis of similarities in the forest fuel load based on the Bray-Curtis distance.

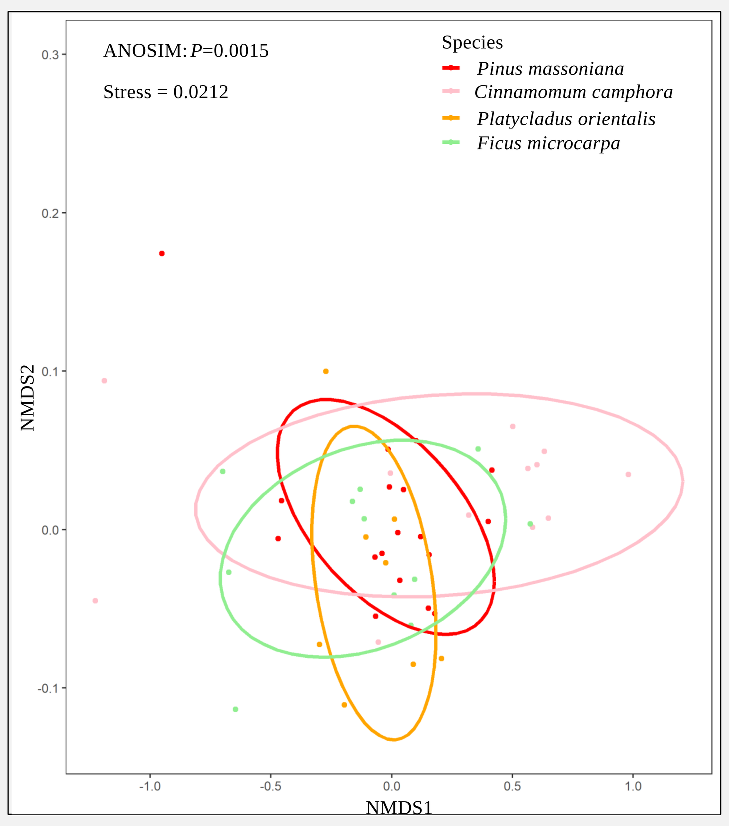

Figure 5. Nonmetric Multidimensional Scaling (NMDS) analysis based on the Bray-Curtis dissimilarity.

Conclusion

- Both the NMDS and ANOSIM results showed that there were significant differences in the forest fuel loads among the different stands, which confirmed the first hypothesis.
- The results confirmed that the spatial distribution of the forest fuel load was dependent on niche-based and random processes, and dispersal limitation was the dominant factor. These results lend support to our second hypothesis.
- The stand factors, canopy density and average tree height, had a significant impact on the variation in the fuel load. The topographic factor, altitude, had a significant impact on the variation in the fuel load.

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