Application of gap and non-gap detection methods for quantifying reference conditions in western North American forests

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Introduction

The importance of understanding the spatial patterns of reference conditions and their influence on stand dynamics is of particular interest throughout the frequent-fire conifer forests of western North America. Throughout these systems presettlement and remnant old-growth stands often exhibit an aggregated tree distribution in uneven-aged patches, except for the random tree arrangement found in a few ponderosa pine (Pinus ponderosa Laws. var. scopulorum) stands on more productive sites. Canopy gaps alternating with tree patches are thought to typify within-forest patterns (e.g., Figure 1) in many frequent-fire conifer forests. Furthermore, this is particularly true for the southwestern ponderosa pine ecosystems where tree gaps filled with grasses and forbs account for the highest level of plant diversity and spatial patterns have been shown to influence forest dynamics and risk of catastrophic, stand-replacing crown fires.

Figure 1: Typical ponderosa pine site illustrating canopy gaps alternating with tree patches ("non-gap" areas) of varying ages.

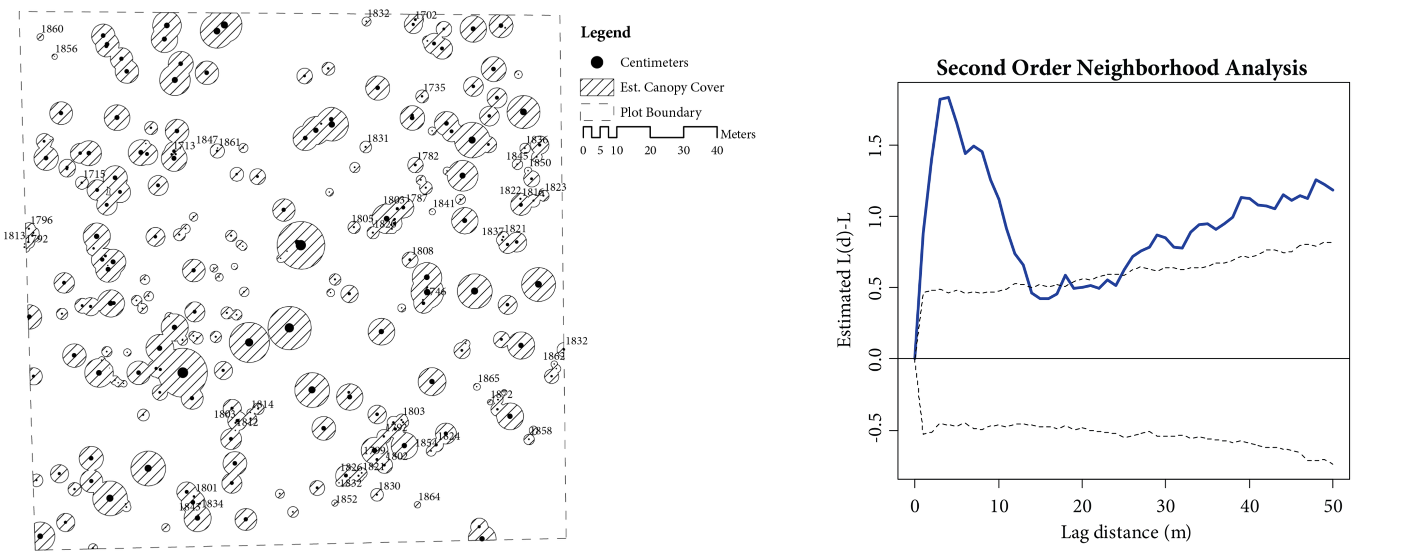

Figure 2: Example study plot map (left) and corresponding second-order neighborhood analysis for ponderosa pine trees (dbh ≥ 9.14 cm) reconstructed as they would have appeared in 1874.

Study Sites and Methods

For this study, we utilized a subset of the network of 50 permanent plots established between 1909-1913 on the National Forests of Arizona and New Mexico (USFS Southwestern Region; now USFS Region 3). The subset examined in this study was composed of 27 permanent plots which were reconstructed to presettlement conditions (1873-1880). In brief, we used historic stem maps and dendrochronological reconstructions to determine the structural reference conditions and stem maps to explore associated spatial patterns..

We examined the application of three analysis techniques used to describe spatial point patterns, namely: 1) second-order neighborhood analysis (Ripley 1977), 2) nearest neighbor clutter removal (Byers and Raftery 1998), and 3) continuum percolation methods (Meester and Roy 1996). Utilizing these methods, we present a range of structural reference conditions for southwestern ponderosa pine forests, focused on metrics such as group density, group size, and trees per group.

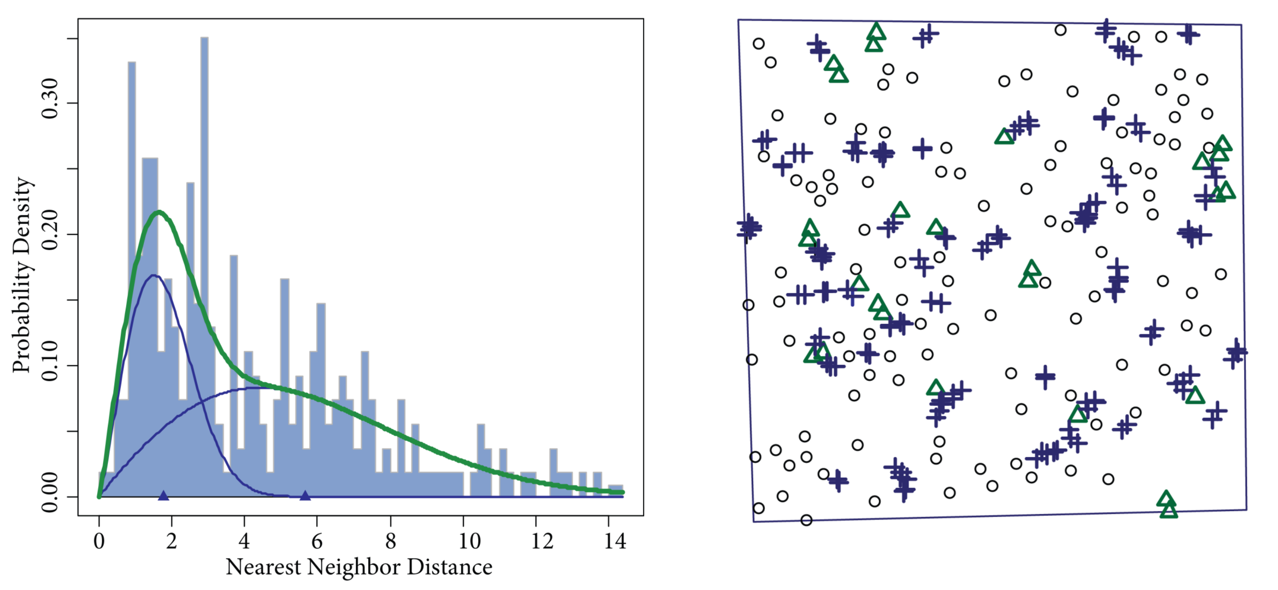

Figure 3: Resulting fit of two gamma distributions (Dark blue lines) to observed nearest neighbor distances (Left) and map illustrating the resulting detection of individual trees (○), trees in groups (+), and borderline trees (△) for an example study site.

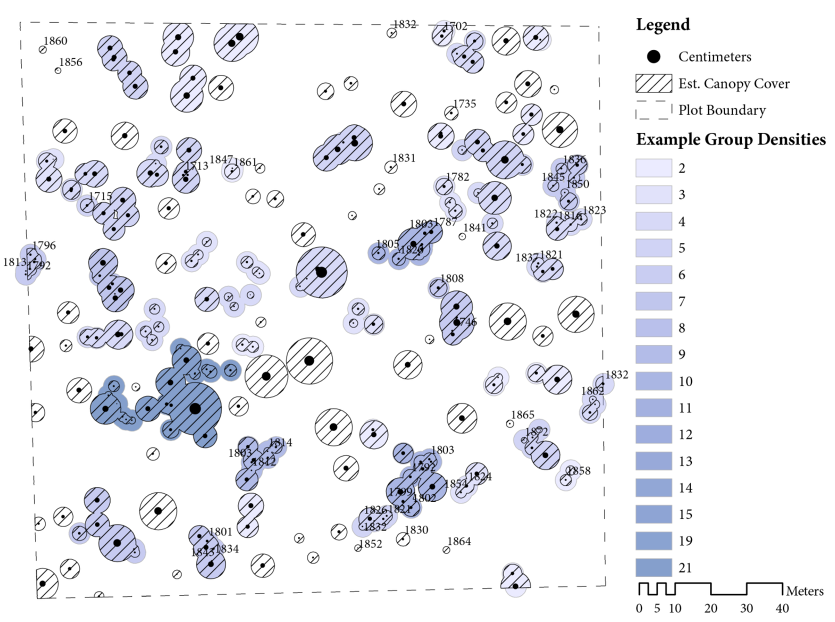

Figure 4: Reconstructed stem-maps for an example plot in Arizona prior to Euro-American settlement showing the location of live trees in 1874 (dbh ≥ 9.14 cm), projected tree canopies, and distinct tree patches (color indicates density) as derived using the continuum percolation method.

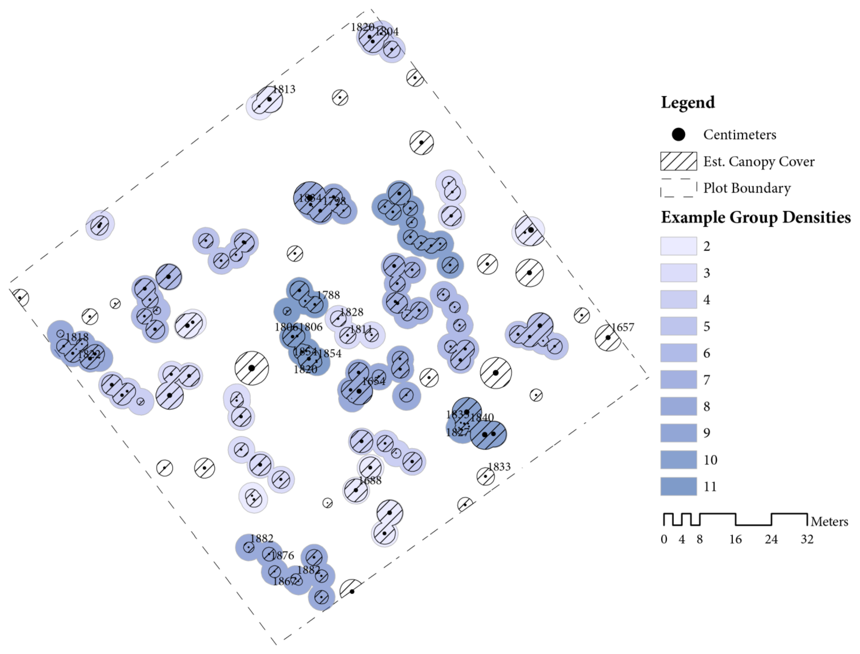

Figure 4: Reconstructed stem-maps for an example plot in New Mexico prior to Euro-American settlement showing the location of live trees in 1880 (dbh ≥ 9.14 cm), projected tree canopies, and distinct tree patches (color indicates density) as derived using the) nearest neighbor clutter removal method.

Figure 6: Spatial patterns in frequent-fire forests were historically maintained by frequent, low-severity fire, illustrating a feedback loop between pattern and process,

Results

Typical patterns and resulting structure (gap and non-gap areas) for analyses using the second-order neighborhood analysis (Figure 2), nearest neighbor clutter removal (Figure 3), and continuum percolation method (Figure 4&5) produced similar (~75%) tree group delineations. The majority of individual trees were members of patches (75% to 84% of the total trees ha^{-1}), and these trees accounted for 51% to 85% of the total basal area ($m^2\ ha^{-1}$).

Using the continuum percolation method, results (Table 1) suggest that historical conditions in ponderosa pine forests exhibited

- As many as 80 tree groups per hectare
- Tree groups ranged between 0.01 and 0.25 hectares
- Tree groups were composed of as few as two and as many as 72 trees

Table 1: Comparison of historical spatial pattern reference conditions for ponderosa pine forest (including data from this study - shaded grey) for areas nearby (southwestern US).

Comparison Reference	Group density (groups/ ha)	Group size (ha)	Trees per group
Cooper 1960		0.16-0.32	
White 1985		0.05-0.72	3-44
Abella & Denton 2009	1-33		2-25
Sánchez Meador et al. 2011	25-67	0.003-0.09	3-24
Sánchez Meador & Moore 2010		0.01-0.1	
Binkley et al. 2008		0.1-0.25	
This Study	24-80	0.01-0.25	2-72

Discussion

The distinguishing structure of ponderosa pine and frequent fire forests throughout western North America is best described as a mosaic of gap and non-gap areas. Managers cannot afford to ignore tree spatial patterns in fire-frequent forest restoration and fuel reduction treatments given the vast geographic scope of ongoing and future operations, and potential consequences for ecosystem function. The management of these highly altered ecosystems is a major challenge for land managers, and the methods presented in this study allow for quantitative spatial information on gap and non-gap patterns of not only reference but current condition. Ultimately, information generated using the approaches outlined in this study may serve to compare changes and establish guidelines to return fire-frequent forest ecosystems to a resilient condition (e.g., Figure 6), and position them to adapt to future climates and disturbance regimes.

Literature Cited

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