Notes and records

Determining patch size

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Introduction

Shrub encroachment, i.e. the increase in density of woody species, is threatening tree-grass coexistence in savannas worldwide (see e.g. Smit, 2004; Wiegand, Ward & Saltz, 2005; Wiegand, Saltz & Ward, 2006). In addition to ecological problems, shrub encroachment creates economic problems, because it reduces the extent of areas suitable for grazing of livestock. In recognition of the importance of spatial and temporal scales for savannas, Wiegand *et al.* (2005, 2006) proposed patch-dynamics as the driving mechanism of tree-grass coexistence in savannas including a naturally shrub encroached phase. In patch-dynamic landscapes, patches are asynchronously cycling between woody and grassy dominance. Evidence for patch-dynamic savannas is accumulating (e.g. Gillson, 2004; Wiegand *et al.*, 2006), but simple methods for the determination of the spatial scale of patches are still lacking. In the present study, we propose a method for estimating patch sizes based on the canopy diameter and the spatial location of individuals and apply it to an example data set from a semi-arid savanna in South Africa.

Material and methods

Method description

To determine the size of patches with the proposed method, canopy diameter and *xy*-coordinates of all shrubs in an area, which is in the shrub-dominated phase of the cyclical succession, are needed. These can be obtained by direct measurement in the field using a tape measure or from aerial photographs and satellite images.

The proposed method is based on a univariate Neyman–Scott cluster process (Diggle, 1983). A Neyman–Scott cluster process is constituted by randomly distributed 'parent' points and 'offspring' points with a bivariate normal distribution relative to the location of the parent. For the Neyman–Scott process, Ripley's *K*-function and the pair-correlation function g (*h*) (Stoyan & Stoyan, 1994) are

$$K(h, \sigma, \rho) = \pi h^2 + \frac{1 - e^{(-h^2/4\sigma^2)}}{\rho}$$

and

$$g(h, \sigma, \rho) = 1 + \frac{e^{(-h^2/4\sigma^2)}}{4\pi\sigma^2\rho},$$

where h is the scale investigated, ρ is the intensity of the parent process (i.e. number of points per area) and σ^2 denotes the variance of the distance between each offspring and the parent (Diggle, 1983).

Cluster analysis of the stem positions produces biased estimates of patch sizes because shrub cover is also determined by the degree of overlap in canopies. Therefore, we developed an algorithm to fill the canopies (approximated by circles with canopy diameter) with points so that the spatial pattern of the canopies could be analysed. With the canopy filling algorithm, the number of points to be distributed within the borders of each canopy circle was calculated as the area of the canopy circle divided by a square area with side length l. l determines the density of points to be distributed. We suggest using the fifth smallest canopy diameter occurring in the data set for l. While smaller values of l lead to unrealistically small patch sizes, increasing l to values greater than the fifth smallest canopy diameter does not change patch size markedly, according to our experience. The calculated number of points is then randomly distributed within the borders of the canopy circle. Shrub canopies with diameters of less than l are represented by one point only with the original coordinates of the shrub. The overall canopy point pattern is then fitted to a Neyman–Scott process to generate the null

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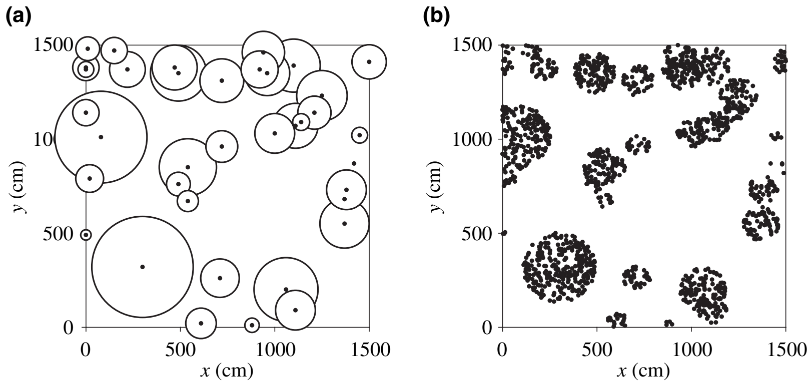

Fig 1 Example of a bird's eye view of one of the 15 × 15 m example plots. (a) *xy*-Coordinates of the locations of all shrubs in the plot (solid point in the centre of every circle). The canopy area is approximated by a circle with canopy diameter. (b) *xy*-Coordinates of the points that were randomly distributed within the borders of the original canopies (see a) to allow for the cluster scale calculation. Truncation of the pattern at the borders of the plot is a prerequisite for the application of the PROGRAMMITA software

model for the confidence interval simulations. The cluster diameter is approximated as 4σ. A confidence level of $P = 0.05$ is obtained when upper and lower confidence envelopes are generated from the fifth greatest and the fifth smallest values out of 199 simulations. We used the PROGRAMMITA software (Wiegand & Moloney, 2004) for the fitting and application of the Neyman–Scott model.

Application example

The canopy-filling algorithm was applied to spatial data from the Pniel study site in semi-arid savanna in the Kalahari thornveld (28°35′S, 24°29′E), 30 km north of Kimberley, South Africa. Within 20 fenced 15 × 15 m plots, we determined the *xy*-coordinates and the maximum canopy diameter of all shrub individuals with tape measures (n = 1077, minimum n = 10 shrubs per plot, maximum n = 167 shrubs per plot). Visual inspection of the pattern of the canopies from a bird's eye view revealed clustered shrub patches (Fig. 1) fulfilling the prerequisite for the application of the proposed method. We analysed all plots separately with a significance level of $P = 0.05$.

Results and discussion

The proposed method is a method for the estimation of patch sizes requiring only information on spatial location and canopy diameters. It is more objective than a morphometric approach of patch size estimation from aerial or satellite pictures or in the field because of the spatial statistical approach. Adding to conventional cluster size estimates (e.g. Plotkin, Chaves & Ashton, 2002), our patch size estimates also include information on canopy cover by including the canopy-filling algorithm.

In the example application, the mean diameter of a cluster approximated 178 ± 226 cm (SD), whereas the maximum cluster diameter was 738 cm, which seem to be rather small patch sizes (K.M. Meyer, K. Wiegand, D. Ward and A. Moustakas, personal observation). Yet, in semi-arid savannas, most interactions occur belowground with root system extents greatly exceeding canopy diameters (root extent >4 * canopy diameter in *Acacia mellifera*, D. Ward, unpublished data; see also Meyer *et al.*, 2005). Thus, real patch sizes may be underestimated in our application. However, if spatial data on root system extents are available, the proposed method can equally well be applied to the estimation of belowground patch sizes. This will lead to larger patch size estimates. Furthermore, the range of possible applications of the proposed method is not restricted to savannas, but can be applied to any patch size estimation problem in vegetation science.

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